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THE
ELECTRIFICATION OF AGRICULTURE
AND
RURAL DISTRICTS

BY
E. W. GOLDING
M.Sc.Tech., A.M.I.E.E., Mem.A.I.E.E.
Lecturer in Electrical Engineering
University College
Nottingham

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EDITORS' INTRODUCTION

TO THE ELECTRICAL ENGINEERING SERIES

It is perhaps not an exaggeration to say that until comparatively recently books on Electrical Engineering subjects could be divided into two well-defined classes, viz. students' textbooks and specialized works for the engineer in practice. Few books were of value to both types of reader, and in the past this state of affairs was perhaps satisfactory enough.

In the opinion of the Editors of this series the situation has now changed considerably. The very rapid increase in both the numbers and magnitudes of the applications of electricity, the greatly extended areas of supply as a partial consequence of the existence of the National Grid, and the far greater complexity of modern life in general have all tended to alter the requirements both of students and of experienced engineers as regards technical literature. It is now necessary that engineers both on the manufacturing and supply sides of the industry shall have a knowledge of a very wide range of subjects, in addition to their own specialized line. On the other hand, young, technically trained engineers entering industry require something more than a mere knowledge of fundamental principles if they are to become of value to their employers within a reasonable space of time.

Fortunately, as a result of the high standard now reached in colleges and secondary schools, a wider course of reading on the part of the more advanced students is nowadays more feasible, and a smaller proportion of the time in engineering colleges is required for the teaching of purely fundamental principles.

Thus the requirements of advanced students and of experienced engineers appear to be more nearly similar than in the past, and it is the object of this series to fulfil this dual purpose. While it is not intended that the books shall be of sole interest to those engineers working in the particular field with which they deal, purely academic aspects of the subjects will not, in general, be discussed.

It will be the endeavour of the Editors to include in the series books upon essentially practical subjects with which more advanced students should nowadays be familiar, and to choose as the authors of these books engineers with a thorough knowledge of their subjects, whether their activities may be in the academic or in the industrial sphere.

To satisfy the needs of readers who may wish to extend their study of any particular branch, the authors of all the volumes in the series will give references to the more important reference works and original publications.

H. COTTON.
E. W. GOLDING.

University College,
Nottingham.
1937

PREFACE

THE subject of Rural Electrification, or, more precisely, the supply of electricity to rural premises, is now receiving a considerable amount of attention. This is not surprising in view of the significance of the rural districts as the seat of the agricultural industry. Agriculture, in this country, as in all other countries of the world, must be regarded as of prime importance to the life of the nation, although for many years past there has been a tendency to forget this and to neglect agricultural interests in concentrating upon the requirements of the more localized manufacturing and transport concerns. It is probably true to say that, with political and economic conditions as they are to-day, at no time in our history has it been more necessary to study agricultural requirements and to ensure that the industry shall be placed in a sound position.

During recent years the depressed state of agriculture and the associated problem of the prevention of the continual transference of labour from the land to the towns has occupied the attention of politicians, and various innovations, such as import duties, marketing schemes, and the insurance of agricultural workers, have been introduced. From the point of view of actual production these remedies are, however, external, and there are many who hold the opinion that they should be accompanied by increased mechanization in an endeavour to reduce production costs. It seems clear that there are two ways of approaching the problem of foreign competition—admittedly one of the difficulties confronting British agriculture. One is to increase the price obtained for agricultural produce by such expedients as tariffs and marketing schemes and the other is to reduce the costs of production. The effect of increased mechanization is in the latter direction, and the part to be played by electricity in this connection may be a very important one.

Taking the broad view, the application of electricity to the manufacturing industries generally has become very extensive, not without good reason, and it seems probable that such application would also benefit agriculture in spite of its somewhat different character. It is significant also that our most successful foreign competitors in the agricultural field have adopted electricity on their farms. Incidentally, the question of increased amenities in rural districts which would result from electrification must not be overlooked.

In this book the author has attempted, in addition to describing the various applications of electricity to farm and rural work, to present a fair review of the whole question in so far as this is possible by one in the electrical engineering profession. It is recognized that opinion is somewhat divided upon the subject of the economy of rural electrification, but, with the existing National Electricity Grid, we have a foundation for such electrification and it seems worthy of earnest consideration.

The widely different aspects of the problem—social, economic, agricultural, and electrical—together with the varying conditions in different parts of the country, cause the author, upon reflection, to wonder whether he has been presumptuous in attempting such a task. His excuse must lie, however, in his genuine interest in the matter and in the possibility that the book may give the reader sufficient information to enable him to reason the question for himself.

With regard to the text itself, the book has been divided into three parts in accordance with the sections into which the subject naturally divides itself. The first part is intended as a general review from the economic and social aspect, the second describes the actual applications of electricity to agricultural and rural work, and the last part deals with the purely electrical aspect. In the first two parts no previous knowledge of electrical engineering is assumed, although it is thought that the electrical engineer will be interested in the applications described in the second part. Two short chapters are included in which some of the more important facts relating to the use of electricity are discussed for the benefit of the non-technical reader.

Wherever possible, both capital costs of appliances and running costs have been given, although it will be appreciated that both are subject to variation with time and locality. Without such costs it is obviously impossible to discuss the economy of electrification. A price of one penny per unit of electricity has been taken throughout, not because this is always the actual price but because it is one which lends itself most easily to calculations of costs when the actual charges are known for a particular district.

It is impossible to produce a book of this description without becoming indebted to a large number of people, and the author wishes to acknowledge, with gratitude, the kindness of many engineers, rural consumers, associations, and manufacturing firms in giving him information upon various branches of the subject. Many acknowledgments have been made in the text, particularly regarding the loan of blocks by manufacturers. To make individual mention here would involve a very lengthy list, but in a special category must be placed Professor H. Cotton, for his encouragement throughout the production of the book, the author's colleagues, Messrs. A. Radford and F. A. Wells, for reading and making suggestions regarding Part I of the book, and to Mr. D. G. Denoon, of Callender's Cable and Construction Co., Ltd., for reading the manuscript of Chapter X.

E. W. GOLDING.

University College,
Nottingham.
February, 1937.

CONTENTS

PAGE
EDITORS' INTRODUCTION v

PREFACE vii

PART I

CHAPTER
I. GENERAL REVIEW 3

II. SOME FACTS RELATING TO BRITISH AGRICULTURE AND RURAL DISTRICTS 8

III. POWER REQUIREMENTS ON FARMS AND IN RURAL DISTRICTS. 19

IV. DEVELOPMENT OF RURAL ELECTRIFICATION—THE PRESENT SITUATION 56

PART II

ELECTRIFICATION FROM THE POINT OF VIEW OF THE FARMER OR RURAL CONSUMER

V. ELEMENTARY ELECTRICAL ENGINEERING 73

VI. ELEMENTARY ELECTRICAL ENGINEERING (*continued*) . 87

VII. ELECTRICITY FOR LIGHTING, HEATING, AND DOMESTIC PURPOSES. 103

VIII. APPLICATIONS OF ELECTRICITY IN AND AROUND FARM BUILDINGS 141

IX. APPLICATION TO HORTICULTURAL WORK . . . 188

PART III

ELECTRIFICATION FROM THE POINT OF VIEW OF THE ELECTRICAL ENGINEER

CHAPTER PAGE
X. FARM WIRING 205
XI. THE PROBLEM OF ECONOMIC SUPPLY TO RURAL AREAS 219
INDEX. 241

PART I

CHAPTER I

GENERAL REVIEW

It is not an exaggeration to say that the application of electricity to agriculture, and incidentally to rural industries generally, is one of the most vital questions of the day not only to agriculturists and electrical engineers, but to the country as a whole. Although there is reason to hope that, as a result of recent political measures and of the general improvement in trade, farming is "on the mend," it is only too well known that during the last few years the industry has been passing through a period of very acute depression. Indeed, with the possible exception of the war years, when conditions were abnormal, the present century has seen a steady decline in agriculture and an attendant and consequential transference of farm workers from the rural districts to the towns in search of more profitable employment in the manufacturing industries. Thus, in addition to the loss of trade due to the reduced purchasing power of the rural population, the country is further embarrassed by the number of former rural workers who now form part of the large unemployed population of the towns. Again, the general reduction of world trade, and the increasing tendency for manufactured goods to be made in those foreign countries which formerly exported raw material to Great Britain and imported from us the manufactured articles, makes it all the more imperative that this country in the future shall be as self-supporting as possible; this is quite apart from the strategic advantage of being self-supporting as regards food in war time. In brief, a nation, like an army, "marches on its stomach," and it seems obvious that the more adequately we can cater for the needs of this nation's stomach by means of home-produced food the better.

Mr. Lloyd George, in his recent speech outlining his programme for national development, was most emphatic on this point: "We have about the best soil in the world; we have the best and most accessible markets; we are compelled now to buy from abroad hundreds of millions worth of produce, most of which could be raised in this country. . . . We had over two million agricultural workers of all kinds when we had about half our present population to feed. We have now about one million on the soil. . . . Let us get back to the two millions."

Turning now to the other side of the question, we in this country have as our heritage an abundant store of energy in the form of coal. On the other hand, scattered over the whole country, we have more than 400,000 farms of various sizes and a considerable number of other rural industrial concerns, in addition to between one and two million dwelling-houses, all of which require power. Electricity provides a means—indeed, the only feasible means—of transmitting to the rural districts a supply of power " on tap " sufficient to satisfy all their power requirements and of enabling them to benefit fully from these coal resources. Electricity is produced in the generating stations from British coal, and this fact alone is a strong point in its favour as compared with the only other source of power and light available in rural districts, namely, oil, which is, of course, a foreign product.

Agriculture, having as its raw material the soil with its inherent fertility, is a business in just the same sense as a manufacturing concern having iron, wood, cotton, etc., as its raw material. At the present time the electrification of almost all other industries has become so complete that there can be no question as to the economic value of such a service. If we consider, for example, the coal-mining industry, which, like agriculture, is one of our greatest and most vital industries and which has been suffering severely during the depression of the last few years, we find ample evidence of its appreciation of the value of electrification. As in the case of agriculture, there have been, and still are, difficult problems to be faced in the electrification of mining, but the great progress made may be judged from the following figures extracted from an article by J. F. Perry[1]:

Number of mines using electricity for both power and light . . .	1,402
Number of mines using electricity for lighting only	76
Number of mines not using electricity	795

This means that 65 per cent. of the mines are using electricity. In the same article the total horse-power in the form of electric motors in these mines is given as 1,725,546, while the average annual increase in electrical horse-power used has been 16,000 h.p. above ground and 18,500 h.p. underground during the five years 1928–1933—five very difficult years from the industrial point of view.

It seems, therefore, reasonable to suppose that an adequate supply of electric power would also be of great benefit to agriculture and the rural industries generally. When, in addition, one considers the increased amenities which electricity would give to the rural districts in the form of clean and efficient lighting and heating, it appears that there is almost a moral responsibility to provide such a supply.

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[1] *The Times*, December 5th, 1933.

It will be realized from the foregoing remarks that rural electrification is to some extent a social question, and although this book is not primarily concerned with social matters, the author makes no apology for introducing this aspect of the subject at various points throughout the work.

So far it has been taken for granted that electricity has not been applied to agriculture to any appreciable extent in this country ; this is largely true, although there are already more farms with an electricity supply than is generally realized, and rural electrification has begun to make progress during the last few years. The reasons for the small amount of progress as compared with that in urban districts and the manufacturing industries are not far to seek. In common with most other questions, the present one depends upon costs. There are, of course, two parties principally concerned, namely, the rural population and the electrical supply undertakings ; both of these must be able to show a profit as a result of electrification before such a service can become an established success. There is no doubt whatever that really cheap electricity would be very generally used by farmers and other rural inhabitants. On the other hand, the cost of supplying a scattered country district is higher than that for an urban district, while the revenue obtainable is not commensurate with the capital expenditure required unless a large proportion of the rural population both takes a supply and uses it freely.

✓Such a project requires, therefore, careful thought and considerable boldness on the part of the distribution engineer before he can offer a supply on terms which, although acceptable to the rural consumers, will only be profitable when a large load has been developed, possibly only after a number of years, when the full benefits of a supply have been realized. It is clear, therefore, that progress must be a gradual process, the willingness of the rural consumers to take a supply and the ability of the engineers to provide electricity at an acceptable price being so largely interdependent.✓

The existence of the National Grid, which is now complete, together with the many statements made in the Press and elsewhere at the inception of the Grid Scheme has, quite naturally, led the rural population to expect an adequate supply of electricity at a low price and, moreover, at a uniform price for the whole country. The fact that the Grid is a national scheme has caused a number of farmers to advance the view that there should be no distinction as regards electricity tariffs between the rural and urban consumers. The uniform letter rate of the Post Office is taken as an analogy. " Why," the farmer asks, " am I required to pay two or three times as much for my electricity as people living within the urban boundary while the Post Office allows me to send a letter either to the next village or to John o' Groat's for the same charge of 1½*d.* ? " Underlying such an argument as this there is, of course, a misunderstanding of the function of the National Electricity Grid. The Grid network connects together electrically the many large electrical generating stations in various parts of the country and so effects considerable economies in *generating* costs. But this is not the end of the matter : the various supply undertakings now purchase their electrical energy from the Grid, and in doing so may reduce their generating costs, but there still remains the problem of distributing the electricity to the consumers in their own districts, and such distribution is responsible for a very considerable part of the total costs.[1] The Grid scheme does little to reduce these distribution costs, so it can be seen that, although the benefit of cheaper generation is passed on to the consumer, it is a mistake to think that the total price per unit can be reduced immediately in proportion to the reduced cost of generation. Much must depend upon the initiative of the engineers in charge of the various electricity supply undertakings and upon their skill in devising cheap, yet satisfactory, distribution schemes. Even so, different areas vary considerably as regards the ease with which their electrical requirements may be catered for : the density of population, the existence or absence of factories or other commercial enterprises requiring power, and the nature and degree of prosperity of the agriculture, are factors which have a great influence upon the success of an electrical undertaking in the area considered, and upon the ease with which it may be profitably supplied. Under present circumstances, therefore, it is scarcely reasonable to expect a uniform charge throughout the country, and, indeed, it is difficult to see how this

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[1] Average figures for the whole of the electrical undertakings in Great Britain as regards capital expenditure are :

Capital expenditure on Generation	44–45 per cent.
Capital expenditure on Transmission and Distribution . .	55–56 per cent.

These figures are taken from official statistics of the Electricity Commissioners.

uniformity could be accomplished by any means short of the complete nationalization of the electrical supply industry. The desirability or otherwise of such nationalization is too big a question to be discussed here, and as there is little prospect of such a step being taken in the near future, we must confine our attention to the present order of things.

As an alternative to electrification by a public supply, there is, of course, the possibility of installing private electrical plants on farms. Such installations are, however, unlikely to become common, since, even if it could be proved that they were profitable as compared with a public supply, there are few farmers who would be prepared to provide the necessary initial capital, and perhaps even fewer who would have both the knowledge and the time to attend to such plants. For this reason private installations have not been considered in the foregoing discussion of the electrification problem, and they will be neglected in the remainder of this book.

In discussing the difficulties to be faced by the electrical supply engineers and the possibility of a uniform charge for electricity, it must not be overlooked that already several thousand English farms are connected to an electrical supply and are using it profitably for many farm processes. Again, many more which lie in the vicinity of existing distribution lines could obtain a supply by application to the local electricity undertaking. Now, while it might be difficult to prove that complete electrification, to the exclusion of all other forms of power (except manual labour) would, under existing conditions and charges for electricity, be profitable and desirable in the case of every farmer and rural industrialist, it would be equally difficult to prove that, with even the highest of the existing charges, no applications of electricity would be profitable. It behoves the rural consumer, therefore, to consider to what extent electricity could be applied profitably in his particular case at the present time and it behoves the supply engineer to encourage such applications as far as possible with the object of building up the very considerable load which could eventually be obtained. As already pointed out, the process of electrification must be a gradual one, but it must surely be considered well worth while if it is instrumental in placing our oldest, and in some respects our most important, industry on a more stable footing.

CHAPTER II

SOME FACTS RELATING TO BRITISH AGRICULTURE AND RURAL DISTRICTS

SPEAKING generally, we have, as a nation, read and thought so much about our manufacturing industries during the past few decades that we are in danger of overrating their importance and of neglecting almost entirely the facts relating to agriculture. Before proceeding further with the subject of electrification, therefore, a brief review of the more important facts in connection with our agriculture and rural districts might not be out of place.

For this purpose data for England and Wales will be kept separate from that for Scotland. The low density of population, the existence of large tracts of mountainous moorland, the generally unprofitable nature of farming activities due to climatic and other considerations, the question of amenities as regards scenery, the presence of abundant potential water-power resources, and the fact that the National Grid Scheme covers only the southern half of the country, are all factors which make the question of the electrification of the rural districts of Scotland very different from that of England and Wales.

From this statement it must not be inferred, however, that rural electrification in Scotland needs no consideration. To the supply company the profit to be obtained from such an enterprise, especially in the northern districts, and the great difficulties to be encountered might certainly render it unattractive, but the question presents a very different aspect when viewed from the standpoint of the rural inhabitants of these districts. Anyone visiting the Western Highlands and observing the almost ceaseless hard work and anxieties of the crofters in these rainy and unfertile districts must realize immediately what a boon an abundant supply of cheap electricity would be to these people. Hay and oats, grown on land manured with seaweed laboriously gathered and carted from the seashore, are cut with the scythe, the hay being tossed, raked, and built into ricks by hand, to remain in the fields for weeks, possibly for months, with frequent spreading in the intermediate period before the weather becomes sufficiently dry to enable the crop to be stacked. In 1934, for example, there were in some districts only six or seven rainless days during the months of August, September, and October.

Again, when carted, the oats are often threshed by small hand-turned machines in the evenings after a hard day's work, the lighting for this, as for other evening work, being quite inadequate. The household's supply of butter is obtained by frequent churnings of small quantities of available milk, while the cooking is carried out over peat fires. It requires little imagination to appreciate the potentialities of electricity for crop-drying, lighting, heating, and general power purposes under such conditions as these if only the all-important question of distribution costs could be settled satisfactorily.

Rural Area and Population

Statistics concerning land areas and populations in Great Britain are given in Table I.

TABLE I

DATA RELATING TO LAND AREAS AND POPULATION IN GREAT BRITAIN

	England and Wales. (*a*)	Scotland. (*b*)	Ratio of (*a*) to (*b*).
Total area (to nearest 100 square miles)	58,300	29,800	1·95
Rural area as a percentage of the total area (approx.). . . .	89 per cent.	99 per cent.	0·9
Total population (to the nearest 100,000)	39,900,000	4,800,000	8·3
Rural population	8,000,000	1,480,000	5·4
Rural population as a percentage of the total population (approx.) .	20 per cent.	31 per cent.	0·65
Average density of population per square mile :			
Urban areas	4,800	10,850[1]	0·44
Rural areas	154	50	3·1
Total	685	161	4·25

From this table it can be seen that the question of rural electrification affects approximately 9½ million people in Great Britain, 8 millions of which are in England and Wales and 1½ millions in Scotland. The difficulties of electrical distribution to these potential consumers are apparent when it is observed that they are scattered over 89 per cent. and 99 per cent. respectively of the total areas of the countries, giving average densities of population of only 154 per square mile in England and Wales and

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[1] Probably somewhat erroneous, due to the small percentage area involved.

50 per square mile in Scotland. Included amongst the rural populations mentioned in the table there are, of course, some rural residents whose occupations are in the local towns, and of the remainder a considerable percentage is not engaged in any branch of agriculture.

Referring to the density of population of 685 persons per square mile for England and Wales *as a whole*, it is pointed out, in the 1931 Census report, that this is " with a possible exception in the case of Belgium, far higher than that of any country of which we have record—much more than double those of a large majority of other countries." Moreover, the population of England and Wales as a whole has shown a steady increase from 1801 to the present time. In the case of Scotland there has also been a steady increase until 1921, while from 1921 to 1931 there has been a fall in the total population of some 40,000. This is accounted for largely by the fall in population of the rural districts and small burghs, the fall in the case of the former being some 67,000, or 4·3 per cent.

The same tendency of the population to move from the rural districts to the towns is evident in the case of England and Wales. In this connection the figures given in Table II are of interest:

TABLE II

VARIATION IN THE RELATIVE PROPORTIONS OF THE URBAN AND RURAL POPULATIONS[1]

Year of Census:	1891	1901	1911	1921	1931
Percentage of total population:					
Urban	72·0	77·0	78·1	79·3	80·0
Rural	28·0	23·0	21·9	20·7	20·0

From this table it can be seen that the percentage rural population has steadily diminished from 28 per cent. in 1891 to 20 per cent. in 1931.

Relative Importance of the Agricultural Industry

Table III gives some information regarding the agricultural industry. It has often been stated that agriculture is the most important industry in this country, as in most other countries in the world : while the words " most important " require, perhaps, some amplification before they can be justified fully, it will be evident, from the information given in Table III, that the numbers of people employed, the capital invested, and the value of the annual production are such as to merit full consideration when the industrial activities of the whole country are considered.

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[1] Extracted from the 1931 Census report.

TABLE III

GENERAL DATA RELATING TO THE AGRICULTURAL INDUSTRY

Capital invested in agriculture in Great Britain (estimated)	£1,000,000,000
Total number of farms and agricultural holdings (England and Wales, 1933)	388,433
Persons engaged in agriculture (England and Wales, 1931 Census):	
Males	1,116,573
Females	55,683
Total	1,172,256
Agricultural workers as a percentage of total rural population	14·7 per cent.
Value of net annual agricultural output for Great Britain	£190,000,000 (approx.)

TABLE IV

NUMBERS OF PERSONS NORMALLY EMPLOYED IN MAJOR OCCUPATIONS IN ENGLAND AND WALES (1931)

	Males aged 14 and over.	Percentage of total.	Females aged 14 and over.	Percentage of total.	Males and females together.	Percentage of total occupied population.
Total occupied population: . .	13,247,333	100	5,606,043	100	18,853,376	100
Persons engaged in personal service (Institutions, Clubs, Hotels, etc.) . . .	462,935	3·5	1,926,978	34·4	2,389,913	12·7
Commercial, Finance, and Insurance .	1,466,587	11·1	604,833	10·8	2,071,420	11·0
Transport and Communications .	1,565,846	11·8	68,899	1·2	1,634,745	8·7
Metal-workers (excluding electroplate and precious metals) . .	1,349,774	10·2	96,120	1·7	1,445,894	7·7
Clerks, Draughtsmen, and Typists .	795,486	6·0	579,945	10·4	1,375,431	7·3
Agricultural occupations. . .	1,116,573	8·4	55,683	1·0	1,172,256	6·2
Mining and Quarrying	966,210	7·3	2,561	0·05	968,771	5·1
Textile Workers .	301,552	2·3	574,094	10·2	875,646	4·7
Makers of textile goods and articles of dress . . .	276,738	2·1	542,809	9·7	819,547	4·4

Table IV gives the total numbers of persons normally occupied (i.e. including those at present unemployed) in the most important industries in England and Wales, the figures being extracted from the Census report of 1931. The industries are arranged in order of precedence on a basis of total numbers of persons employed in them.

This table shows that agriculture is the sixth on the list of our major occupations as regards the total of persons occupied, having a total of 1,172,256 workers and a percentage of 6·2 of the total occupied population.

By comparing this total number of agricultural workers with the total rural population of England and Wales given in Table I, we find that 14·7 per cent. of the rural population is so occupied. It is obviously of great importance that this basic and vital industry shall be lifted from its present depressed state

Agricultural Wages and Prices

It is instructive to consider the wages of agricultural workers during the period since the war. The average weekly wage, in England and Wales, for agricultural labourers has varied during this period within the limits of £2 6*s*. 10½*d*. and £1 7*s*. 9*d*.,[1] the average value for the whole period being of the order of 31*s*. or 32*s*.; and even so, farmers complain that the present rates of wages are responsible for many of their difficulties. It is indeed true that these rates are almost double the pre-war wages, while the prices of agricultural produce are now only some 6 per cent. above pre-war prices. Again, labour costs may comprise as much as one-third of a farmer's total expenses. Taking the agricultural workers' point of view, these low wages have been largely responsible for some 230,000 workers leaving the land during the past twenty-seven years.[2]

Now, the fact that the value of home-produced agricultural produce in post-war years has been only about 37 per cent. (gross output) of the total value of food consumed by us annually must be due, to a large extent, to the fact that such home-produced food is more expensive than imported food, even though it is admitted that certain foods cannot be grown here from climatic considerations. In addition, the recently imposed protective duties have, of course, the effect of increasing the price of imported food. The facts point to the conclusion that we have two alternatives: either we must accept in this country a lower standard of living—which is of course very undesirable—or we must have cheaper production in the agricultural industry. While it must be admitted that our farming generally is far from inefficient, it is clear that we must be to the fore as regards up-to-date methods of cheapening production. "Cheap labour and protection simply mean the possibility for a number of employers to continue working with obsolete and bad machinery; but . . . the cheapest produce is obtained with high wages, short hours, and the best machinery." [1] Kropotkin made this statement some twenty years ago in writing of industry generally, but it applies with particular force to present-day British agriculture: cheap labour (as compared with that in other industries), long hours, and a certain amount of protection we certainly have, but they barely enable farmers to continue working in the face of foreign competition, which is assisted in so many cases by efficient, electrically driven farm machinery.[2] And in this connection it must be stated here that the idea, which is fairly commonly accepted, regarding absurdly cheap electricity supplies abroad is not generally justifiable. Mr. R. Borlase Matthews, who is the pioneer of electro-farming in this country and has made a very exhaustive study of the subject, has stated on several occasions that there are many districts on the Continent in which electricity is more expensive than in most parts of Great Britain. He gives as a rough average figure on the Continent 4*d*. per unit for power purposes and 7*d*. per unit for lighting.[3] These charges would be considered rather expensive in this country, yet they have not deterred Continental farmers from using electricity extensively

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[1] See *A Primer of Agricultural Economics*, by Sir H. Rew.

[2] According to a Ministry of Agriculture report on *The Agricultural Output and the Food Supplies of Great Britain*, 1929, the number of agricultural workers in 1908 is estimated as 1,400,000.

Foreign Competition and the Necessity for Reorganization

The Milk Marketing, Pig Marketing, and other similar schemes will ensure to the farmer a fair and uniform price for the products concerned, but many farmers consider that such schemes alone are insufficient and that increased tariffs on imported produce would provide the only solution to their present difficulties. Now, it is true that such tariffs would enable our farmers to compete with the foreigner and would result in home-produced food forming a higher percentage of our total food consumption. But, if they are to bring this about, tariffs must increase the cost of living, and we, a nation relying so largely upon our exports, cannot afford such an increase, since it would necessitate increased wages in our manufacturing industries, and so, by raising the cost of production, react on our exports. It seems, therefore, that, although tariffs may be regarded as necessary as a temporary measure to enable British agriculture to recover, the real solution lies elsewhere.

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[1] P. Kropotkin, *Fields, Factories and Workshops.*

[2] The Ministry of Agriculture and Fisheries Report on *The Agricultural Output and the Food Supplies of Great Britain,* 1929, gives the net agricultural output (after allowing for the value of purchased materials contributing to this output) as £108,600,000 in 1907, representing 13·9 per cent. of the total net output of British industry as a whole, whereas, at £191,700,000 in 1925, this had fallen to 10·7 per cent. of the total. The report states that "the main conclusion to be drawn . . . is that although, except from the point of view of employment, the actual importance of agriculture in Great Britain has not declined in the last twenty years, yet its relative importance, compared with other industries, has sensibly diminished."

[3] R. B. Matthews, *Electro-Farming,* p. 32.

TABLE V[1]

NET OUTPUT PER PERSON EMPLOYED IN VARIOUS INDUSTRIES

	Pre-war. £	Post-war. £	Percentage increase.
Agriculture	77·6	149·8	93
Mines and Quarries . . .	123·7	177·4	43
Iron, Steel, etc.	105·6	199·3	89
Textiles	76·7	178·0	132
Clothing	63·7	155·6	144
Food, Drink, etc.	160·4	370·6	131
Paper, etc.	104·1	269·4	159
Timber	83·1	188·8	127
Building, etc.	83·8	207·4	148
Public Utilities	110·8	222·2	100
Other trades	129·3	275·1	113
Average (excluding agriculture and mining)	97·2	217·6	124

Sir E. J. Russell, a well-known authority on British agriculture, wrote recently : " Agriculture is the business of supplying to-day's food demands by methods suited to to-day's economic conditions "[2] ; and in the same article he stresses the necessity for improved and up-to-date farming methods and the tendency of the younger generation of farmers to adopt such methods, accustomed as many of them are to the use of machinery in the form of motor vehicles, wireless sets, and so on. It appears certain that we could produce in this country, by more intensive farming, a much greater proportion of our total food consumption than at present. We must, however, employ methods of increasing the production per head of labour, which, as can be seen from Table V, has increased since pre-war times by a smaller percentage than that in other industries, with the exception of mining and the iron and steel industry.

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[1] From the Ministry of Agriculture and Fisheries Report on *The Agricultural Output and the Food Supplies of Great Britain*, 1929.

[2] *Daily Mail*, November 9th, 1934.

The three main factors of production on a farm are land, labour, and capital, as represented by machinery, etc. The relative amounts of these used in a particular country will depend upon their relative costs ; thus, if land is cheap and labour relatively expensive, the land is cultivated extensively, i.e. the size of farm will be great compared with the number of men employed. In England until recently land has been relatively expensive and labour cheap, but now the labour factor has also become more expensive, and in the interests of economy we tend to use labour more sparingly.

Since maximum production per head is obtained by the assistance of mechanical power it follows that increased mechanization of farming is essential. What proportion of such mechanization can best be in the form of electrical power, depending, as it does, upon the conditions at each individual farm, must be for the farmer himself to decide. It is one of the objects of this book to give some assistance in making this decision.

The Agricultural Marketing Acts, which have resulted in the present system of Marketing Boards, were passed with the object of securing co-operation of agricultural producers as regards marketing so as to ensure a fair price for their products and increase the purchasing power of the rural population. These Acts form, therefore, first steps in the reorganization of agriculture, and on this foundation, and within a protecting system of tariffs, should be built up a more efficient system of farming with greatly increased mechanization and electrification as its main features. It would be fatal to us as a nation if British agriculture were allowed to fall into decay, as it appeared to be falling until quite recently. Table VI gives an analysis of the agricultural land in England and Wales, and shows the decline in the proportion of arable land and the increase in the proportions of permanent pasture and of rough grazing. From this table it is clear that the land has been steadily going out of cultivation. Again, Table VII compares home production and net imports of food for pre-war and post-war periods. It can be seen from this that in several kinds of produce there has been an actual reduction in the amount of home produce, while in all cases

TABLE VI[1]

CHANGES IN CULTIVATION OF AGRICULTURAL LAND, 1925–1933

Year.	Arable	Permanent pasture	Rough grazing as returned by occupiers	Total agricultural land
	Thousands of acres			
1924 .	10,929	14,948	—	—
1925 . .	10,682	15,073	3,920	29,675
1926 . .	10,548	15,128	3,939	29,615
1927 . .	10,310	15,280	3,997	29,587
1928 . .	10,109	15,396	4,048	29,553
1929 .	9,948	15,490	4,083	29,521
1930 . .	9,832	15,547	—	—
1931 . .	9,582	15,701	—	—
1932 . .	9,367	15,840	4,153	29,360
1933 . .	9,250	15,870	4,193	29,313

In addition to the acreage of rough grazing, as returned by occupiers, there is an area of common land or mountain and heath land grazed in common estimated at approximately 1,199,000 acres

TABLE VII[2]

COMPARISON OF QUANTITIES OF HOME-PRODUCED AND IMPORTED FOOD

Product	Pre war period			Post war period.			Increase (+) or decrease (—) in the percentage of home production
	Home production	Net imports	Home production as a percentage of total	Home production	Net imports	Home production as a percentage of total	
			Per cent			Per cent.	Per cent.
Wheat, Barley, and Oats (000 tons)	4,881	6,748	42	4,336	6,509	40	— 2
Meat (Beef, Mutton, and Pig meat, including lard) (000 tons) .	1,168	1,303	47	1,125	1,704	40	— 7
Poultry (000 cwt)	776	596	57	918	540	63	+ 6
Eggs (millions) .	1,416	2,956	32	2 263	2,816	45	+ 13
Butter (000 cwt) .	715	4,839	13	674	5,379	11	— 2
Cheese (000 cwt) .	737	2,327	24	857	2,868	23	— 1
Potatoes (000 tons) .	3,016	307	91	3,245	522	86	— 5
Fruit (kinds normally grown in Great Britain) (000 cwt) . .	8,130	4,449	64	8,921	8,383	51	— 13

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[1] From Ministry of Agriculture and Fisheries Agricultural Statistics

[2] The figures given in the table are abstracted from Ministry of Agriculture and Fisheries Report on *The Agricultural Output and the Food Supply of Great Britain*, 1929.

but those of eggs and poultry there has been a decrease in the percentage of the home-produced food. It is interesting to note that the two increased percentages have been in a branch of the industry in which intensive methods of farming have been adopted.

Summary

Summarizing this brief outline of the conditions in present-day British agriculture and in rural districts, we find that :

(*a*) In England and Wales 8,000,000 people, or 20 per cent. of the total population, and in Scotland 1,480,000 people, or 31 per cent. of the population, are rural inhabitants, the densities of population in rural districts being 154 and 50 per square mile respectively.

(*b*) As a percentage of the total population the rural population of England and Wales has fallen from 28 per cent. to 20 per cent. during the last forty years.

(*c*) Approximately 1,172,000 persons (14·7 per cent. of the total rural population, or 6·2 per cent. of the total occupied population of the whole country) are engaged in agriculture on 388,433 farms and agricultural holdings in England and Wales, while the capital invested in agriculture is of the order of £1,000,000,000.

(*d*) The average weekly wage of English farm labourers is about 33*s*. compared with 18*s*. in 1914, while the prices of agricultural produce are of the order of only 6 per cent. above pre-war prices.

(*e*) The value of home-produced food is only about 37 per cent. (gross output) of the total value of our annual food consumption.

(*f*) The relative importance of agriculture as compared with other industries has diminished appreciably during the last twenty years.

(*g*) The Marketing Schemes, together with the imposition of certain protective import duties, have paved the way for a general reorganization of British agriculture.

(*h*) The net output per person employed has not increased as much since pre-war times as that in most other industries, while the area of cultivated land and quantity of home-produced food as a percentage of the quantity imported have both diminished appreciably during recent years.

The conclusions drawn from these facts are, briefly :

(*a*) The number of rural inhabitants is such that any method of increasing their purchasing power and of improving conditions in the rural districts is worthy of consideration, especially if it tends to prevent the undesirable diminution of the percentage of rural population which has been observed during recent years.

(*b*) The British Agricultural industry is of great importance, and some degree of reorganization, including increased mechanization and more intensive cultivation to increase the production per man employed, is necessary in order to check its decline in relative importance as compared with other British industries.

(*c*) The number of men employed on English farms at present is not so great (probably owing to the comparatively high wages as compared with pre-war) that no profitable field could be found for the human labour which might be displaced by the increased application of mechanical power.

CHAPTER III

POWER REQUIREMENTS ON FARMS AND IN RURAL DISTRICTS

If we neglect the few instances of the use of windmills and water-wheels, we have as alternative forms of power on farms :

(*a*) Manual labour ;
(*b*) Animal (chiefly horse) labour ;
(*c*) Oil engines ;
(*d*) Electricity.

Human power, or manual labour, is not strictly comparable with the other forms, since there are obviously many jobs on farms which no animal or even the most ingeniously designed machine can perform. For such jobs, and in order to direct the application of the other forms of power, men will always be necessary. Our discussion of power requirements should, therefore, be based on the consideration of these forms of power as assisting human labour and rendering it more productive rather than displacing it.

Again, horse labour cannot be compared very strictly with mechanical power in the form of an oil engine or electric motor, since, speaking generally, horses are suited only to work which is in the nature of draught or traction, whereas oil engines, in the form of tractors, can be used for both tractive and stationary work. Electricity is especially suited to stationary work in and around the farm and farm buildings. Its application to work on the farm land—which is principally tractive work—is less easy, although it has been accomplished, especially abroad. The general application of electricity to such work in this country cannot be entirely ruled out, although it must depend very largely on comparative costs and upon the degree of electrification which is eventually attained in the other classes of farm work.

Another aspect of the question arises when we consider lighting and heating. Both light and heat are forms of energy, and since " power " is defined as the " rate of doing work " or " rate of expending energy," these must be taken into account in the general discussion of power requirements. From these points of view oil and electricity are the two competing commodities in rural districts, if we exclude the relatively small amounts of gas which may be available in the vicinity of towns. There is little difficulty in proving that electricity has great advantages over oil for lighting and heating purposes.

In this section of the book it is not proposed to enter into a detailed discussion of relative costs of the different forms of power, this being left to be dealt with in Part II. It is desirable, however, to attempt to estimate the possible or probable power requirements of farms and rural districts as a total in order to discover the magnitude of the possible load to be obtained in relation to (say) the total output of electricity by authorized electricity supply undertakings in the country.

As far as possible, this estimation will be dealt with under three headings: (*a*) farms alone; (*b*) rural districts alone; (*c*) farms and rural districts together.

(*a*) Power Requirements on Farms

Types of Farms

The power requirements of farms depend upon the type of farm considered as well as upon its size. Thus, included within the general term " farm," we may have an arable farm or a dairy farm, a fruit farm, a poultry farm, or a stock farm. Again, market gardening, bee-keeping, rabbit farming, and, possibly, even fur farming may come under the same general heading, although it might be better to class some of these as rural industries. In many cases, of course, farms fall under several of these headings and may be referred to as mixed farms. It will be apparent that the power requirements per acre of the various types must vary considerably.

In Table VIII various types of farms in England and Wales are compared from the point of view of numbers of persons employed on them, the figures being obtained from the 1931 Census Report.

From the table it is seen that although, as might have been expected, the general or heavier type of farming accounts for the large majority of agricultural workers, the numbers employed in the lighter types of farming are by no means negligible.

Size of Farm

Table IX gives an analysis of the farms in England and Wales on the basis of acreage. It can be seen from this that 63·7 per cent. of the total farms or " agricultural holdings " have an acreage not exceeding 50, and are therefore classified as " small-

TABLE VIII

NUMBERS OF PERSONS EMPLOYED ON DIFFERENT TYPES OF FARMS AND AGRICULTURAL HOLDINGS

Type of farm.	Number of persons employed.		
	Males.	Females.	Total.
General farming and stock-rearing (excluding fruit and poultry farming)	750,547	41,637	792,184
Poultry farming	22,771	4,262	27,033
Market gardening and fruit farming	50,265	3,790	54,055
Flower and seed growing and nursery gardening	41,973	5,853	47,826
Other undefined gardening . .	26,118	293	26,411

TABLE IX

ANALYSIS OF THE SIZES OF AGRICULTURAL HOLDINGS IN ENGLAND AND WALES (1933)

Acreage.	Number of farms.[1]	Percentage of total number of holdings.	Total acreages as a percentage of total acreage (estimated).
1–5 . .	69,864	18·0	0·8
5–20 . .	100,591	25·9	5·0
20–50 . .	76,901	19·8	10·6
50–100 . .	62,380	16·0	18·4
100–150 . .	32,183	8·3	15·8
150–300 . .	34,644	8·9	30·7
Above 300 . .	11,870	3·1	18·7
Total . .	388,433	100·0	100·0

holdings." A "small-holding" is defined legally as one whose area is between 1 and 50 acres.

Now, while the type of farm has a considerable influence on the power requirements, the size must also have its effect in the case of any particular type of farm. It is difficult to generalize, but it is obvious, for example, in the case of arable farms, that while a large arable farm might justify the capital expenditure on a threshing machine, such expenditure might be unjustifiable in the case of a smaller farm of the same type. The power requirement exists in both cases, and it may even happen that the power required per acre of cultivated land is the same in each case, but, considering the question from the point of view of installation of power plant, the practical difficulty of justifiable capital expenditure arises in the case of the smaller farm. This question is discussed more fully on p. 27.

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[1] Abstracted from the Agricultural Statistics (1933) issued by the Ministry of Agriculture and Fisheries.

Actually the threshing in such a case would be done by contract, and the necessary power would probably be obtained from coal or oil, according to the type of drive used for the thresher. If, in the future, electrification of farms becomes general, it may be that the contractor's threshing machine will also have an electric drive, in which case the power will be taken from the farmer's electric mains and his consumption of electricity will be considerably increased.

Returning to the question of the type of farm, it will be realized that, even in the case of small-holdings, there is a vast difference in the power requirements of a cottager with a few acres for a cow and the growing of vegetables necessary for home consumption as compared with an up-to-date and intensively cultivated market garden. In the first case, the cottager may be a farm labourer who attends to his own plot in his spare time, and thus has little capital to spare for machinery, while in the second case, the use, if the market garden is electrified, of such equipment as soil and greenhouse heaters, water heaters, high-power lamps for intensive illumination, etc., may be responsible for a considerable power load. Thus it can be seen that the size of the holding alone is very little guide as to its potential power demand. Although in point of actual numbers the small-holdings form a large percentage of the total, the total acreage occupied by the various sizes of farms is very important.

In Table IX an estimation is made of the percentage of the total acreage occupied by farms of various sizes. The acreages were obtained by multiplying the arithmetic average of the limits of size (e.g. 3 acres in the case of farms between 1 and 5 acres) by the number of farms of that size. Although such an estimation is admittedly somewhat inaccurate, the percentages obtained will be of the right order. In Fig. 1 the percentage numbers of farms of different sizes and also the percentage acreages occupied by them are drawn out for comparison. It will be realized from this figure how important it is, when considering the typical size of an English farm, to be clear as to the basis upon which the importance of a particular size is to be judged. Thus, considering percentage *numbers*, 79·7 per cent. of the farms are under 100 acres, although, as can be seen from the *acreage* diagram, the

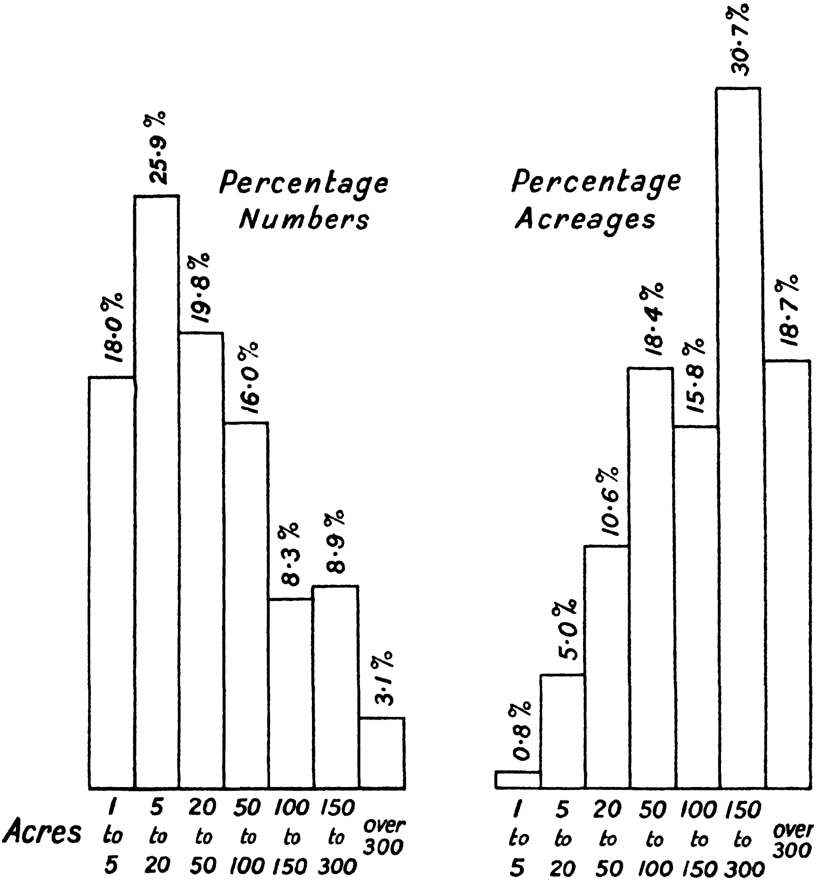

FIG. 1.—PERCENTAGE NUMBERS AND ACREAGES COVERED BY FARMS OF DIFFERENT SIZES IN ENGLAND AND WALES.

remaining 20·3 per cent. occupy approximately 65 per cent. of the total area.

Influence of the Type of Farm upon its Size

In Fig. 2 an attempt has been made to show the influence of the size of a farm upon the gross output per acre and upon the number of men and horses employed per 100 acres. These curves are based upon various published records[1] for different sizes of farms,

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[1] Quoted in *A Primer of Agricultural Economics*, by Sir H. Rew, and in *Large and Small Holdings*, by Prof. H. Levy.

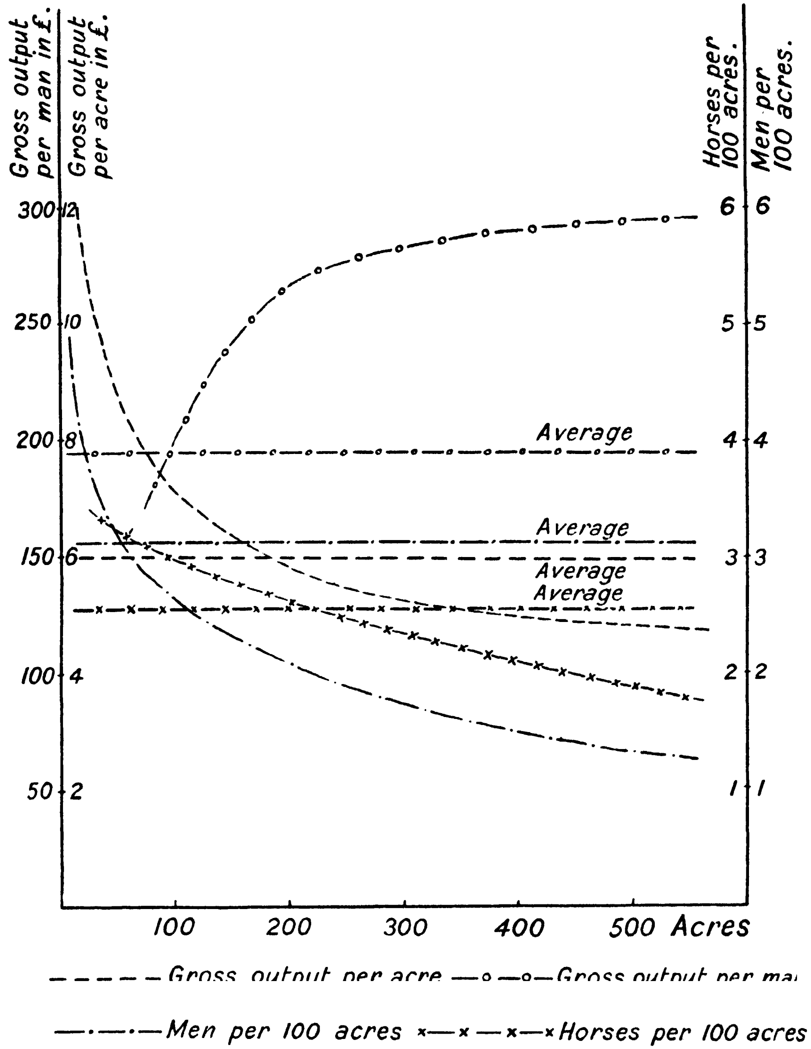

Fig. 2.—Influence of Size of Farm upon Output and Labour.

but they are composite curves, and the values are adjusted to be roughly in accordance with the average values of the various quantities for England and Wales under present-day conditions, these average values being given in the figure. The reader is recommended to note the *shapes* of the curves rather than the actual values, although the latter are not likely to be very much in error.

These shapes indicate that as the size of a farm increases, the men and horses employed per 100 acres and the value of the gross output per acre all decrease, while the value of the gross output per man increases. Obvious conclusions from these curves are that the small-holdings are more intensively cultivated, the numbers of men and horses employed and the value of the gross output per acre all being high, whereas the larger farms employ more extensive cultivation. In the latter case, either the type of farming is such as to demand only a comparatively small quantity

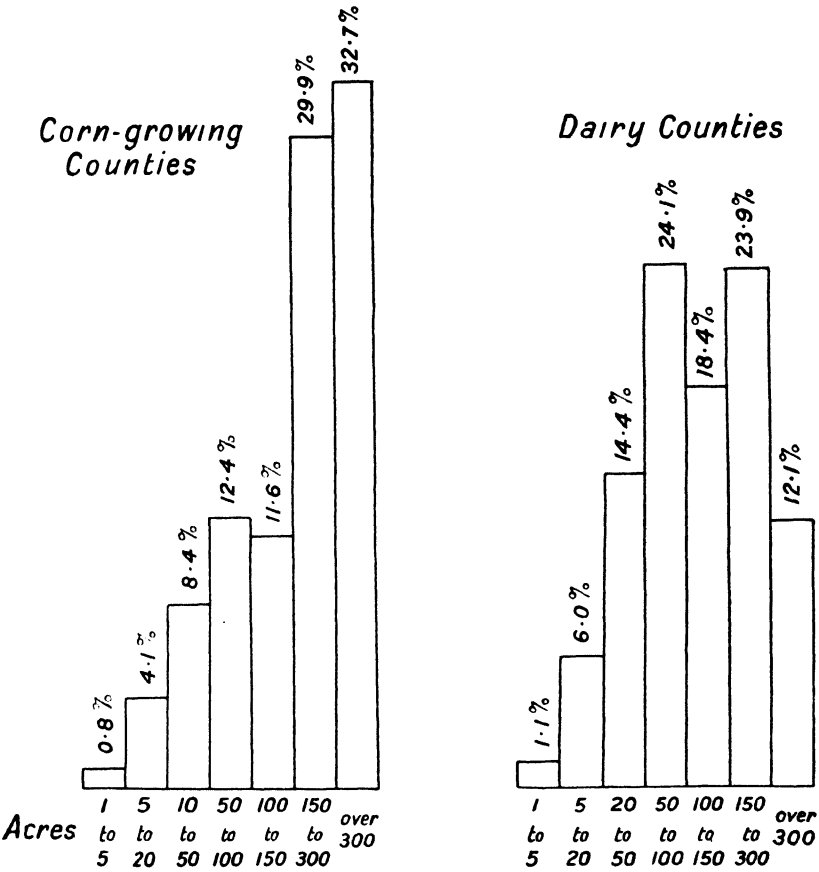

FIG. 3.—INFLUENCE OF TYPE OF FARM UPON ITS SIZE.

of labour, or else labour-saving machinery is more generally used, with a reduced number of men employed as a result. In actual fact both of these factors enter into the case, and this leads us to consider the question of the type of farm as related to size.

Now, it might be thought that the curves in Fig. 2 would be more instructive if they applied to one type of farming—corn growing, for example. It would not have been possible, however, to have obtained results for sizes of corn farms varying between the limits of about 20 acres to 500 or 600 acres, since the simple fact is that corn farms with an acreage as low as 20 are practically non-existent, the common size of such farms being very much higher. Again, results for dairy farms with an acreage over 200 or 300 would have been difficult to obtain, since the common size of such farms is considerably less than this. In this connection the diagrams in Fig. 3, based on the Agricultural Statistics, 1933, are of interest. These show the percentages of the total cultivated acreage occupied by farms of different sizes. Diagram A gives average results for the corn-growing counties,[1] while diagram B gives similar results for the dairying counties[2] in England. From this figure the conclusions may be drawn that corn farms are most commonly more than 150 acres in extent, while dairy farms usually have an acreage of between 50 and 300.

It may be stated broadly that for corn-growing, mixed farming, pedigree stock breeding, and potato growing the large farm has great advantages, while smaller farms are more suitable for fruit and vegetable growing, poultry farming, and general stock breeding, including dairy farming. Levy[3] points out that the reason for this is that the former types of farming require intensive application of capital and permit a large amount of substitution of machinery for manual labour, while the latter require more intensive cultivation and a special quality of labour and individualized attention.

Load Factor

Another question which must be considered in regard to the influence of the size of a farm upon its type and upon the power requirements is that spoken of by engineers as the " load factor."

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[1] I.e. counties in which more than 25 per cent. of the total area under crops is devoted to corn growing: Cambridge, Essex, Hertford, Huntingdon, Lincoln, Norfolk, Suffolk, Yorkshire (East Riding).

[2] I.e. counties in which there are more than 14 dairy cows per 100 acres (average number for the whole of England = 8·5 per 100 acres): Cheshire, Derbyshire, Dorset, Lancashire, Somerset, and Staffordshire.

[3] H. Levy, *Large and Small Holdings.*

This may be defined briefly as the ratio of the actual energy used to that which would be consumed if the available power plant were continuously worked at its maximum capacity. It is clear that any power plant must be used freely if its capital cost (with consequent interest and depreciation charges) and its maintenance cost are to be justified. On farms whose only " power plant " is the horse this is especially true, since the cost of upkeep is practically the same whether it is used often or seldom.

In the case of very large farms there is little difficulty in finding sufficient work throughout the year for the horses kept and for whatever tractors, oil engines, or electric motors are installed, provided the latter are selected and applied judiciously. For example, assuming the farm to be large enough and to have sufficient corn land to justify the use of a threshing machine, the motor or engine driving the thresher can be used to drive a grinder or other farm machinery when not used for threshing. Again, the necessary capital is more likely to be available on a very large farm than on a smaller one.

The smaller the farm becomes, however, the greater the difficulty in finding such alternative uses for power plant until, in the case of holdings of only a few acres, the use of tractors must be ruled out and the use of even one horse may be unprofitable. Unless, therefore, some form of co-operation is adopted between a number of such small farms, any type of farming which requires an appreciable amount of ploughing and other similar high-power work on the land cannot be undertaken. In such cases the extent of the land under actual cultivation tends to be only such as can be dug by manual labour with a spade, and in addition the crop cultivated or the live-stock produce must be more valuable than that on a large farm in order that the small quantity produced may support the occupier of the holding.

Another important point in connection with this question of load factor is that, when once one particular form of power plant, such as a horse or oil tractor, has been adopted for certain power purposes on the farm, it may be good economy to use it for other power purposes for which it is not fundamentally so suitable as some alternative form of power. This is especially so in the case of the small farm keeping (say) one horse : the horse is necessary for carting and general transport purposes, such as journeys to the local town or railway station, and, once installed, it is probably cheaper to use it for cultivation of the land in preference to any other form of power, however cheap the latter may be. At the same time, it must not be overlooked that even in this case there are certain power requirements, such as the driving of machines in the farm buildings, for which the horse would not be suitable.

On a large farm the application of the most economical and most suitable form of power to each particular kind of work is obviously much more feasible, so that there may be room for horses, oil tractors, and electric motors, each applied to the particular jobs for which it is the most economical form of power.

From these considerations it would appear that the tendency in the *immediate* future as regards forms of power is likely to be :

(*a*) For small farms : horse labour on the land and electricity for power in the farm buildings and for lighting and heating in the house and buildings.

(*b*) For medium-size farms : oil tractors and horses for land work and transport respectively, and oil tractors for the large power jobs in the buildings. Electricity may be used for the smaller power jobs in the buildings, for which tractors would be very uneconomical and unsuitable, and for lighting and heating purposes.

(*c*) For large farms : horse labour for transport work, oil tractors for field work, and electricity for all work in the farm buildings and for lighting and heating.

These suggestions as to development are made on the assumption that the problem of producing types of electrically driven machines which are readily applicable to work on the land will not be solved in the immediate future. It has already been stated that under existing conditions electricity is more applicable to stationary work in the farm buildings than to work of a tractive nature on the land. The main difficulty is, of course, that of providing the supply to the machine by a sufficiently flexible method. From this point of view an electrically driven plough or cultivator is at a disadvantage as compared with one driven by an oil tractor, which, of course, carries its fuel on board instead of having to collect it from a stationary supply. Various electrically driven ploughing equipments have been used with varying success in Continental countries, but up to the present none of these have been adopted in this country. With the increase of electrification in farming, however, there is little doubt that there will be carried out on this subject research work for which the incentive has hitherto been lacking. Given a reasonably cheap supply it can be shown without much difficulty that the use of electricity for field work is an economic possibility, and the author considers that the absence of electrically driven cultivating machinery at present is due to technical difficulties of adaptation and not to excessive costs.

It is stated above in (*a*) and (*c*) that electricity will most probably be used for work in the farm buildings in the cases of small and of large farms, in addition to its use for lighting and heating on all sizes of farms. Reference to Fig. 1 will show that the small farms are most important from the point of view of numbers, while the large farms occupy the largest percentage area, so that the possibility of the decreased use of electricity in the farm buildings in (*b*), above, owing to the use on this size of farm of tractors for some of the large power jobs in the building, is not very important.

The Magnitude of the Power Demand on English Farms

From what has been said regarding the influence of the type and size of farm, taking into account, also, the individual opinions of farmers as to the merits of different forms of power, and, again, realizing that such matters as whether the farm is cultivated by the farmer and his family alone or with the help of hired labour influence the power requirements, it will be understood that the estimation of the possible total power demand is a somewhat formidable task.

For this purpose it is necessary, at the outset, to distinguish between the power—animal, mechanical, and, in comparatively few cases, electrical—which has been used in the past before considering what electrical power demand there may be in the future. In this latter connection it must be emphasized that the estimate should be a conservative one which might serve to indicate the possible load in the near future, since little purpose would be served by attempting to estimate the load eventually to be obtained after many years of development. As regards animal power, the Agricultural Statistics (1933) give the number of horses used for agriculture in England and Wales as 645,611. Now, although some of these horses may be replaced by the increased use of oil tractors, for the reasons given in the preceding paragraph it is unlikely that any appreciable portion of their work will be carried out by electricity in the immediate future.

Considering mechanical power, the Report on Electricity Supply in Rural Areas, issued by the Electricity Commissioners in 1928, gives the total number of engines in use on farms in England and Wales in 1926 as 81,535, with an estimated total horse-power of between 500,000 and 600,000. In an appendix to this report is given data supplied by the National Farmers' Union in 1928 for mechanical power (as distinct from electric) installed on 42 English farms of various types and sizes. An analysis of these figures shows the difficulty of carrying out an estimation such as that in hand, since we find that the horse-power installed per 100 acres on these farms varies from 0·4 h.p. to 27·6 h.p., while for no particular size or type can consistent results be obtained. The two limiting cases quoted are interesting and illustrate this perfectly. The first is a mixed farm (dairy produce, breeding and fattening cattle, etc.), and has a total acreage of 600 acres, of which 400 acres are arable and 200 acres grass. One 2½-h.p. oil engine is installed for grinding and crushing, a *hired* steam-engine being used for threshing and chaff-cutting. The second farm is of the same type—mixed, chiefly arable—and is of 246 acres, 160 of which are arable and the rest grass. The horse-power installed is 68, used for threshing and grinding, ploughing, cultivating, etc. In addition, electricity is generated for lighting purposes on the farm.

It is obvious that neither of these values of horse-power per 100 acres can be taken as representative, and under such circumstances it appears that the best that can be done is to take an average for the 42 farms. This average gives almost exactly 5 h.p. per 100 acres, if we exclude hired power and reckon the horse-power of tractors (where not stated) as 25.

Mr. S. E. Britton, the Engineer of the Chester Corporation Electricity Supply undertaking, in a paper published by the British Electrical Development Association, states that 300 farms in his area have discarded 107 engines of various types, aggregating 793 h.p., and that these have been replaced by electric motors aggregating 1,584 h.p. Since the total area of these farms is given as 22,586 acres (averaging 75 acres per farm), we find that the installed horse-power (non-electric) was 3·5 per 100 acres, while the installed horse-power (electric) replacing them is 7 per 100 acres. This result agrees reasonably well with the previously obtained figure of 5 h.p. per 100 acres.

In another appendix to the Electricity Commission Report mentioned above, data are given for the electrical installation on 54 farms having an electricity supply in 1928. Only 26 of these farms had electric motors installed for power purposes, the rest taking a supply only for lighting, heating, and domestic purposes. The average horse-power installed per 100 acres in the case of these 26 farms is 4·4. So far as can be ascertained from the data given, none of this power was used for field work, i.e. it was used entirely in the farm buildings. When this figure of 4·4 h.p.

per 100 acres for the farm buildings alone is compared with the average figure of 5 h.p. per 100 acres previously quoted for non-electrified farms, and which referred to the power installed for all purposes, including a certain amount of tractor power for field work, it is seen that the two figures agree fairly closely. As in the previous analysis, the individual figures obtained for the horse-power per 100 acres of farm land were quite inconsistent, so that only the average figure can be taken as informative. It is probable, indeed, that figures for horse-power installed in the form of electric motors will always be rather more variable for farms of the same size and type than would be the case if oil-engine power were installed. The cause of this lies in the natures of the two different forms of drive: oil engines (with the exception of tractors) are most likely to be used to drive line shafting catering for a number of barn machines, or else permanently coupled to a single machine; in addition to these uses, electric motors are specially suitable for use as portable machines. This last fact introduces the possibility of considerable variation in the power installed, since, although from some points of view it is better to have self-contained units, each with its own driving motor, considerations of cost may encourage the use of one portable motor for use with a number of different machines. Incidentally, it might be well to point out here that, although electrical power is at present used very little for field work, the power required in the farm buildings varies with the acreage of the farm, although perhaps not in direct proportion to this acreage. We are justified, therefore, in speaking of the power per 100 acres, even when considering only that required in the farm buildings.

Lighting

The Electricity Commission Report already mentioned gives also the number of electric lamps both in the farm-houses and buildings for the 54 electrified farms whose power installations have been discussed above. The numbers given, converted to numbers per 100 acres, are plotted separately in Figs. 4 and 5, the former being for the farm buildings and the latter for the farm-houses. While, as might be expected, considerable variation for farms of any particular size is indicated, probably owing to varying costs of electricity and of installation in different districts, to the lack of capital in some cases, and to varying conceptions of what constitutes adequate illumination, certain definite characteristics are distinguishable. Thus the points plotted in Fig. 4 show a tendency to remain independent of the size of farm, there being

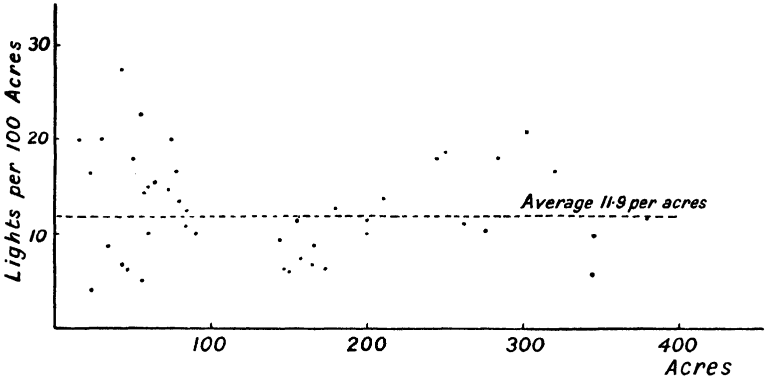

FIG. 4.—LIGHTS PER HUNDRED ACRES (FARM BUILDINGS ONLY).

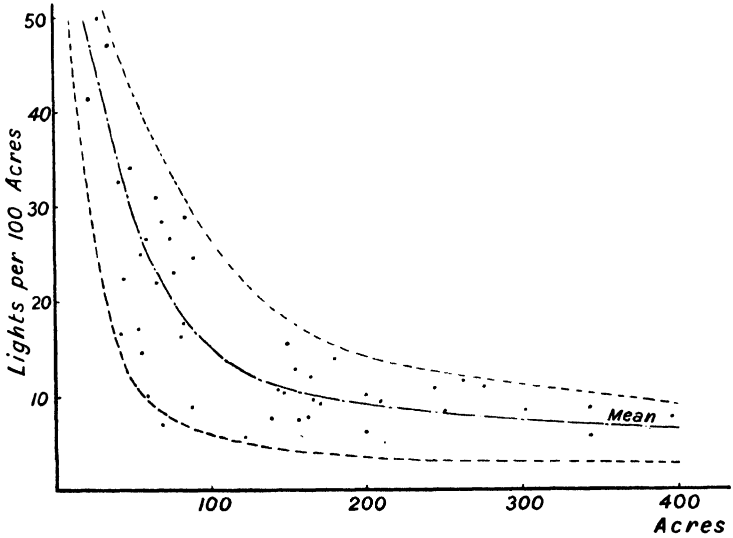

FIG. 5.—LIGHTS PER HUNDRED ACRES (FARM-HOUSES ONLY).

no rise or fall in the number of lamps per 100 acres as the acreage increases. Hence, since the number per 100 acres is practically constant, we find that the actual total number of lamps in the outbuildings on any farm is roughly proportional to the acreage. This is not surprising, since the area covered by the buildings must be roughly proportional to the total acreage of the farm. The calculated average number of lamps per 100 acres (shown on the graph) is 11·9 for the 54 farms under consideration. Fig. 5

shows a marked decrease in the number of lamps per 100 acres as the area increases. This means that the actual numbers of lamps in the farm-houses are much less proportional to the size of the farm. Such a result, again, is not surprising, since, although the size of the outbuildings must be roughly proportional to acreage, the size of the farm-house will not increase nearly so rapidly with acreage. It appears that about 15 lamps will be required in a small farm-house and about 25 in a large one.

Total Power

In addition to the power for driving barn machinery, there are many applications of electricity in and around the farm which have not been mentioned so far, such as motor-driven water and manure pumps, milking machines, water heaters, dairy appliances, etc., etc. These applications will be dealt with in Part II of the book, together with a detailed consideration of electrically driven appliances in general.

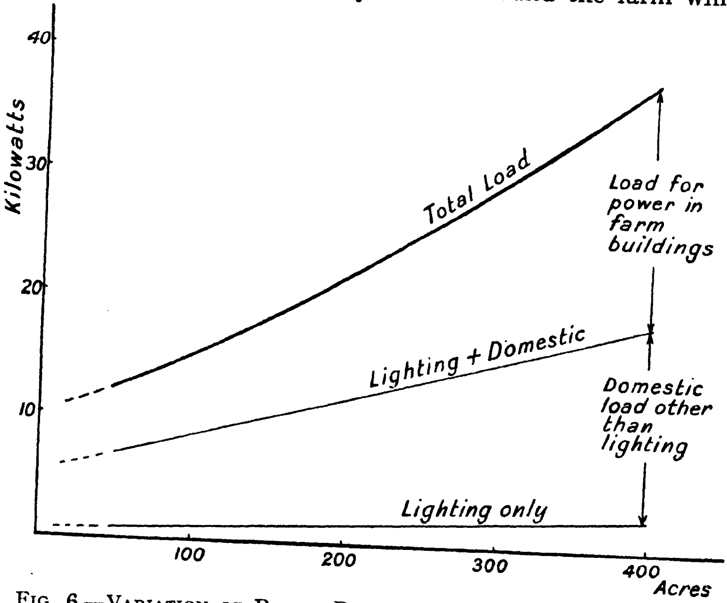

Fig. 6.—Variation of Power Requirements with Size of Farm.

The domestic load, exclusive of lighting, is an important one, and is obtained from the use of electric cookers, electric fires, irons, kettles, etc. To obtain some idea of the power load obtainable, Fig. 6 has been drawn. In this figure the power is expressed in kilowatts (the electrical unit of power). One kilowatt is equivalent to very nearly $\frac{4}{3}$ h.p. This has been done to simplify the calculations in the case of electrical plant such as lighting and heating appliances whose capacities are so expressed in practice.[1] For the purpose of the diagram the lamps installed have been assumed to have an average "wattage" of 30 watts ($\frac{3}{100}$ kilowatt).

From the figure the relative importance of the various sources of the total power load may be judged. In this connection it should be stated that, while the values for lighting are not likely to increase very much, both the domestic load and especially the power load may be increased considerably in the normal course of development. In estimating the extent of the load for power purposes, it was assumed that multi-purpose portable motors would be used, except in cases such as those for water pumps and milking machines, for which portable motors are not generally suitable. Without wishing to be over-optimistic, therefore, the author feels that the total load figures given in the diagram should be taken rather as minimum values than as the limiting values obtainable. It is certain that there are many electrified farms in this country already whose installations have greater capacities than those indicated in the diagram.

In an attempt to estimate the total kilowatts or horse-power which might be required, assuming for the moment that *all* farms in the country took an electricity supply and that their installed capacity varied with size as indicated in Fig. 6, Table X has been drawn up, the numbers of farms being taken from Table IX, p. 21.

TABLE X

POSSIBLE POWER INSTALLATIONS ON FARMS IN ENGLAND AND WALES

Size of farms (acres).	Number of farms of this size.	Kilowatts capacity per farm.	Total kilowatts.	Total horse-power.
1 to 5 . .	69,864	7	490,000	654,000
5 to 20 . .	100,591	8	805,000	1,073,000
20 to 50 . .	76,901	10	769,000	1,026,000
50 to 100 . .	62,380	12	750,000	1,000,000
100 to 150 . .	32,183	15	483,000	645,000
150 to 300 . .	34,644	22	762,000	1,017,000
Above 300 . .	11,870	38	450,000	600,000
		Totals . .	4,509,000	6,015,000

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[1] The values given in kilowatts in the figure can be converted to horse-power by multiplying by $\frac{4}{3}$.

The totals arrived at, namely, approximately 4½ million kilowatts, or 6 million horse-power, are obviously in excess of the actual values attainable. In obtaining these totals we assumed that *all* farms would take an electricity supply and utilize it to the extent indicated in Fig. 6. However desirable this may be, it would be absurd, of course, to take it as a working basis in estimating the actual power which might be installed. It is difficult to prophesy as to what percentage of this total capacity might be installed in the near future, but these figures show the order of the possible demand, and if we take only one-third of these totals to show what might be aimed at, we have the very considerable values of 1½ million kilowatts, or 2 million horse-power. When one considers the figures (already quoted) given by the Electricity Commission Report (1928) for the total power equipment on farms in England and Wales, namely, 500,000 to 600,000 horse-power in 1925–6, and considering also that this presumably does not include any appreciable power for heating, lighting, and domestic uses, the figures mentioned above appear quite reasonable, although it may take a number of years for the development of this large load.

It must not be overlooked, however, that these figures relate to *installed* capacity ; the power equipment will not be fully used at any given time, even in daytime, so that the maximum demand will be, of course, only a fraction of these totals. The total amount of the possible installed capacity is of interest to manufacturers of electrical equipment, but it is the maximum demand for power at any given time which is more important to electricity supply undertakings.

Annual Consumption of Electrical Energy

It is pointed out above that the capacity of the electrical equipment installed on farms is of importance to a supply undertaking, in so far as it indicates what amount of power may have to be supplied at any given time by the rural supply system. Some methods of charging for the electricity supply take into account the capacity of the plant installed. Such methods, referred to as " two-part " tariffs, make a fixed charge based on this installed capacity, together with a charge for the energy actually used. In these methods, and in all other methods of charging, the energy actually used is taken into account, and is an important item.

The energy consumption is measured in kilowatt-hours (kWh.), usually referred to simply as " units." One kilowatt-hour, or 1 unit, is the energy consumed when a power of 1 kilowatt is utilized for 1 hour. Thus, for example, an electric fire, whose rated capacity is 3 kilowatts, will consume 3 kilowatt-hours (or units) in 1 hour, 6 units in 2 hours, and so on. Again, since 1 horse-power is equivalent to ¾ kilowatt, a 5 horse-power motor will consume (neglecting any losses in the motor itself) 5 times ¾ units per hour, i.e. 3¾ units per hour. It is very important to realize the distinction between power and energy. Briefly, the energy consumed is obtained by multiplying the power by the time for which the power is used.

In practice the time for which the motors driving machinery in the farm buildings are used per week is small. Mr. R. W. L. Phillips, Borough Electrical Engineer of Bedford, in whose area a Rural Demonstration scheme, inaugurated by the Electricity Commissioners, has been launched, gives some interesting information on this point in an article in *World Power.*[1] It was found that motors on some farms were used for only some two hours per week at full load, the reason given by the farmers being " that their cake-crushers, root-cutters, and other machines were able to provide enough cattle food in an hour or two for a week's requirements, and that the motor saved many hours hitherto spent in getting the engine away." This being the case, it is difficult to estimate annual energy consumption from a knowledge of the capacity of the power plant installed—much more difficult, for example, than in the case of the consumption in a factory, in which case most of the power plant is in almost continuous use during the working day. Information regarding energy consumption is available, however, and is given below. Since the various sources of information give data in different forms, it cannot well be condensed into a single table.

Commencing with what appears to be one of the largest consumptions recorded in the information at the author's disposal, Mr. V. Z. de Ferranti, in an article in the *Manchester Guardian* of February 5th, 1935, quotes the case of a completely electrified 200-acre farm, producing mainly milk and eggs, which has an annual consumption of 52,000 units, about 40,000 of which are consumed in the farm-house.

An analysis of 1,007 farms in Great Britain, carried out for the purpose of a Report to the Electricity Commissioners,[2] disclosed the facts that, while 682 of these farms had (in 1927) a consumption per farm of less than 1,000 units per annum, 311 farms had a consumption of between 1,000 and 10,000 units, while 14 each consumed more than 10,000 units per annum. Of these last the consumption in one case was over 110,000 units per annum.

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[1] March 1933.

[2] *Report of Proceedings of Conference on Electricity Supply in Rural Areas,* 1928.

From this analysis we may safely draw the conclusion that the 682 with the lower consumption were (in 1927) using electricity for lighting purposes only or, at least, that no appreciable amount was being used for either power purposes or domestic heating and cooking. Farm-houses may be expected to use about the same amount of electricity for lighting and domestic purposes as a middle-class house in an urban area, and the annual consumption in such houses is usually from 100 to 300 units for lighting only, and from 1,000 to 3,000 units when electricity is used for heating and other domestic purposes. Since most small consumers take a supply initially for lighting purposes only, it is probable that many of these farms had been receiving a supply for only a comparatively short period. Consumptions of less than 1,000 units per annum cannot therefore be regarded as the limiting or "saturation" value of the consumption in the cases of these farms.

The average consumption per farm for the whole of the 1,007 farms was 1,445 units per annum. In the same report it is stated that 136 farms, whose consumption could be subdivided into that for power purposes and that for lighting and domestic purposes, had a total annual consumption of 304,095 units, of which

TABLE XI

ANNUAL CONSUMPTION OF ELECTRICITY ON FARMS IN THE CHESTER AREA

Farm acreage.	Type of farm.	Date when first connected to the supply.	Annual consumption (1933).	Annual consumption per acre.
			Units.	Units.
17	Poultry	1928	10,719	630
140	Dairy, sheep . . .	1929	24,783	177
210	Dairy	1925	33,447	159
260	Dairy, stock, and poultry .	1929	27,152	104
347	Dairy, stock, and poultry .	1926	32,949	94·8
211	Dairy, sheep, pigs, and poultry . . .	1926	19,356	91·7
100	Dairy, poultry . .	1928	8,262	82·6
47	Stock, poultry . .	1929	2,744	58·5
145	Mixed dairy . . .	1927	7,292	50·2
227	Dairy	1925	6,420	28·2
240	Dairy	1928	2,741	11·4
		Total .	175,865	
	Average annual consumption per acre .			90·5

196,895 units were for power purposes. This gives an average per farm of 2,240 units total, or 1,450 units for power only.

Mr. S. E. Britton, the Electrical Engineer of the Chester Corporation Electricity Undertaking, has given[1] information regarding electrified farms in his district. The figures in Table XI are abstracted from his paper, the data being given here in a somewhat condensed form and being rearranged.

In this table the farms are arranged in descending order according to the annual consumption per acre, which, it will be noted, varies between the very high value of 630 units per acre for a poultry farm of 17 acres, and 11·4 units per acre for a dairy farm of 240 acres. It should be pointed out that, although not stated in the paper, some of these farms have probably been chosen to show the high consumptions per acre which have been attained in certain cases. Moreover, the Chester district is somewhat favourably situated as regards electricity supply, and great efforts have obviously been made to obtain the agricultural load. The consumptions on these farms cannot, perhaps, be regarded as typical of what may be attained in other districts, in which conditions of supply and the methods adopted by supply companies may be different. They serve, however, to indicate what development is possible under suitable conditions.

It will be noted, also, that the date of connection to the supply has been given in each case. This is an important matter, since there is a distinct tendency in most cases for the consumption to rise year by year after connection to the supply. The following figures, taken from the same paper, are interesting :

TABLE XII

PROGRESS MADE DURING 5 YEARS IN THE CONSUMPTION OF ELECTRICITY ON 12 FARMS IN THE CHESTER AREA

Year.	Total units per annum.	Annual consumption per farm.
1928–9 . . .	42,000	3,500
1929–30 . . .	67,000	5,580
1930–31 . . .	142,000	11,820
1931–2 . . .	145,000	12,100
1932–3 . . .	185,000	15,400

The same tendency is evident in the case of the Bedford Demonstration area already mentioned. The data for this area, given in the following table, is based on figures given in the 14*th* *Annual Report of the Electricity Commissioners.*

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[1] *Five Years' Progress in the Electrification of Agriculture around Chester*, published by the British Electrical Development Association.

TABLE XIII

ANNUAL CONSUMPTION OF ELECTRICITY ON FARMS AND HORTICULTURAL PREMISES IN THE BEDFORD DEMONSTRATION AREA

Year.	Number connected at end of year.	Units consumed during year.	Average annual consumption per farm.
1930–1 . .	38	40,777	1,075
1931–2 . .	122	87,600	720
1932–3 . .	182	175,645	965
1933–4 . .	202	266,932	1,320

It should be noted that the averages given here in the last column are lower than the actual averages, since they are calculated from the number of consumers connected at the *end* of the year, so that not all of these consumers will have taken a supply throughout the full year.

Summarizing, we find, from the data given in the preceding tables, that when large numbers of farms have been considered, the average annual consumption per farm some three or four years after the date of connection has been between 1,400 and 2,300 units.

Two further sets of figures giving results of the same order are :

(i) A consumption of 579,719 units per annum on 300 farms in the Chester area [1] giving an average annual consumption per farm of 1,932 units. The average acreage of these 300 farms was 75, so that the annual consumption per acre averaged 25·8 units.

(ii) An average consumption of 1,163 units per annum on 2,485 farms whose consumptions were investigated by the Electricity Commissioners in 1930.

It is only fair to point out that much of the information given above is now necessarily somewhat out of date. Very considerable developments in electric cooking, water heating, and other domestic uses of electricity have taken place during the last few years, and it is only reasonable, on this account alone, to assess the average load obtainable in the future as somewhat higher than that indicated by the above data. The actual value of this average annual consumption must depend upon a number of factors, amongst which some of the more important are :

(i) The type of farming which is most common in the area considered, and the prosperity of the farms in the area.

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[1] S. E. Britton, *loc. cit.*

(ii) The method of charging for energy adopted by the supply authority and the average price per unit.

(iii) The energy and initiative of the officials of the supply undertaking in building up the farm load.

(iv) The facilities which are available in the area in the form of assisted wiring schemes and hire or hire-purchase arrangements as applied to motors, cookers, and other electrical apparatus for farm use.

It is unfortunate that comparatively few of the analyses of consumption which have been carried out give the average acreage of the farms considered, so that the very useful figure of average annual consumption *per acre* cannot be obtained in these cases. Consumptions per acre in excess of 100 units per annum were given in Table XI, with an average for the 11 selected farms of 90·5 units per acre. The average figure for 300 farms in the Chester area has also been given as 25·8.

The Electricity Commission Report on Rural Electrification (1928) gives estimated figures of consumption as under :

For an arable and stock farm of about 300 acres (with threshing), 10,350 units per annum, or 34·4 units per acre per annum.

For a similar type of farm of 100 to 150 acres (without threshing), 4,320 units per annum, or 34·6 units per acre per annum.

For a dairy farm of 300 acres (with milking machine), 15,410 units per annum, or 51·3 units per acre per annum.

For a dairy farm of 100 acres (with milking machine), 6,600 units per annum, or 66 units per acre per annum.

These figures of realizable consumption per acre do not appear excessive when compared with those given in Table XI. We may conclude, therefore, that a consumption varying between 30 and 60 units per acre per annum may be obtained with reasonably full use of electricity without any application to work on the farm land. Mr. R. Borlase Matthews has estimated [1] that an additional consumption of 45 to 60 units per acre per annum would be required for ploughing and cultivating purposes. As already pointed out, however, there is little prospect of this latter consumption being required in this country in the immediate future.

Now, the total area of land under crops and grass (excluding rough grazing) in England and Wales in 1933 was approximately 25 million acres, so that if only 20 per cent. of this land had an annual consumption of (say) 45 units per acre, the total annual consumption would be 225 million units. Again, taking 20 per cent. of the total number of farms in England and Wales, this total would correspond to an average annual consumption of 2,900 units per farm.

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[1] *Journal of the Institution of Electrical Engineers*, vol. 64, p. 803.

It can be seen from this that if a large percentage of English farms are eventually electrified, and if the consumptions per acre given in Table XI are obtained generally, the total consumption on farms might be about 1,000 million units. For comparison it might be stated that the total number of units generated by authorized electrical undertakers in Great Britain in 1935–36 was 18,415 million units.

(*b*) Power Requirements in Rural Industries

The term " rural industry " is a somewhat loose one, and may be applied to at least three different classes of industry or business. Thus there are certain small industries which are almost essentially rural in character and which are carried on by the proprietor, together with two or three men (e.g. blacksmith). There are also industrial concerns, such as garages and building and contracting establishments which, while existing in the country districts, are not essentially rural. Again, there are, scattered over the country, many factories and industrial concerns of a larger kind, employing, perhaps, 50 or 100 men. Some of these, such as brickworks and quarries, are truly rural industries, but must be considered separately from the foregoing industries when the question of power requirements is under consideration.

These larger concerns may represent a considerable potential load on an electricity supply system, so much so, indeed, that they may alter the whole aspect of the supply problem in the particular area. Thus, a supply company, when running out distribution lines to supply these comparatively large loads, may find it possible to supply, also, smaller consumers whose chances of obtaining a supply would otherwise have been somewhat remote. The existence of such concerns in a supply area may thus be considered an asset to both the supply company and the rural district. The number of these larger industrial concerns is not, however, sufficiently great for them to influence all supply undertakings in this way, and they must be ruled out when considering a typical rural area. Incidentally, the existence of an electricity supply in a district will tend to encourage the establishment of these larger industrial concerns.

The power requirements of industrial concerns of the second of the three classes mentioned above will not differ greatly from similar concerns in urban districts, and these concerns, which include butchers, bakers, and village shops of all kinds, can best be considered together with private houses, etc., in assessing the total load obtainable in an area.

As regards the first of the three classes to which the term " rural industry " most properly applies, a pamphlet entitled *The Rural Industries of England, Scotland, and Wales* is issued by the Rural Industries Bureau.[1] The following extract from this pamphlet is of interest : " There are still about two hundred smiths, seventy-five wheelwrights, and fifty saddlers to a county. Scattered over England are 4,000 basket-makers ; in Wales there are a hundred rural textile factories ; in the Highlands and Islands of Scotland are hand-loom weavers ; in Southern England hurdle-makers ; besides which there are thatchers and rush-plaiters, potters and bowl-turners, broom-makers and rake-makers. In the aggregate these crafts represent an important industry, giving employment to many men and capable of employing many more."

In all there are at least fifty separate small industries of an essentially rural character, such as those mentioned in this extract. While there is little point in making a complete list of these, the following deserve mention in addition to those already quoted : Straw rope-making, cider-making, vegetable and fruit preserving, pottery-making, cabinet-making, toy-making, and, in some districts, lace- and hosiery-making.

It is difficult to assess with accuracy the power requirements of these different industries or the load which might be obtained from them if an electricity supply were available. Information is available, however, concerning certain cases and is given below :

Blacksmiths' Equipment

The following machines may be driven by electric motors in a blacksmith's workshop : forge blowers ; drilling machines, stationary and portable ; hack-sawing machines ; metal-turning lathes ; lawn-mower grinders ; emery grinders and grindstones.

The horse-power required in such a shop will probably be about 5.

Woodworkers' Equipment

While in a small general-purpose woodwork shop only the first three machines may be necessary, it is possible that the following machines may be installed: circular saw; planing machine; band saw; mortising machine; boring and tanging machine; wood-turning lathe; fret machine; sanding machine; moulding machine.

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[1] The author is indebted to the Rural Industries Bureau and to its Technical Adviser, Mr. S. L. P. Bewsher, for some of the following information concerning rural industries.

The horse-power required is as follows[1]:

Circular saw for cross-cutting: horse-power varies from 2 for 18-inch diameter to 8 or 9 for 36-inch diameter.

Circular saw for ripping: horse-power varies from 2½ or 3 for 18-inch diameter to about 10 for 36-inch diameter.

Surface planing machines: horse-power varies from 2½ or 3 for surfacing up to 9 inches width to 4 or 5 up to 15 inches width.

Band saw: horse-power varies from 2 or 2½ for a 24-inch saw to 3 or 4 for a 36-inch saw.

There is thus a probable total requirement of at least 10 h.p. Incidentally, a Rural Industries Bureau pamphlet, *The Country Woodworker and his Shop*, contains the following statements in regard to power plant for such a shop: "As a general rule there is nothing to beat electric power, *if it is available*, for driving woodworking machinery, whether for speed, capacity, regularity and sweetness of running, operative convenience, or—unless the local price for current is very high—economy of working. If more than one machine tool is installed, a separate motor to drive each one is better than counter-shafting."

For butchers and sausage-manufacturing establishments, chopping and mincing machines fitted with 1- or 2-h.p. motors are in use where electricity is available.

Mixing machines for bakers and confectioners are fitted with electric motors of ⅛ to 2 h.p. according to the size of the machine.

Power supply to such rural industries is likely to be more profitable than the supply to a farm, owing to the much longer hours of use of the machines installed. It has been suggested that the availability of electricity on small farms might encourage the undertaking of certain non-agricultural work, possibly in connection with some of the rural industries already mentioned, at times when little work can be carried out on the land. On small Continental farms, such work as weaving and woodworking is carried on fairly commonly as a side-line, and we have a precedent in Scotland in the weaving and knitting done by the crofters. The adoption of such work by English farmers to any appreciable extent may be doubted, but the possibility will exist if a reasonably cheap supply of electricity becomes available, and there is much to be said for such a combination of industrial or manufacturing work with agricultural pursuits. It would appear that a suitable organization for the encouragement of such work must be formed before much progress can be made in this direction.

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[1] *Small Power Plant for Farm and Workshop*, Rural Industries Bureau, Pamphlet No. 26.

As regards the total consumption of energy by rural industries, Mr. R. B. Matthews [1] has stated that this is about 25 to 30 per cent. of the purely agricultural consumption.

(*c*) Total Consumption of Electricity in Rural Districts

In the preceding paragraphs the energy consumption on farms and in rural industries has been mentioned. In addition to these there is, of course, a large number of private residences of various types whose inhabitants are potential consumers, and this domestic load is an important factor in rural electrification. Together with these, churches, railway stations, and institutions may provide an appreciable load. Finally, scattered over the country are many pumping installations for domestic and public water supply and land drainage. With regard to the latter the Ministry of Agriculture and Fisheries in 1928 gave the following data for 140 drainage authorities responsible for the drainage of about 716 square miles : 178 pumping engines, 114 of which had an aggregate capacity of 9,067 h.p. These were principally driven by steam or oil, but of recent years electrically driven pumping installations have been erected in a number of places, and there is no doubt that such work provides an appreciable potential load.

Considering the purely domestic load, while it must be admitted that the capacity to pay for electricity is less in the case of the rural dweller than in that of the urban consumer, with the exception of the inhabitants of large country houses, an important feature of the case is the absence of appreciable competition in the form of gas for lighting and heating purposes. Again, the absence of so many of the amenities which are enjoyed by the urban dwellers causes the rural population to appreciate electricity more than the townsfolk, and it is usually found that rural consumers will use as much electricity as they can possibly afford.

As pointed out in the Electricity Commissioners' Report on Rural Electrification, there are at least four methods of assessing the potential demand for electrical energy in rural districts :

(i) Per head of population.
(ii) Per consumer.

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[1] *Journal of the Institution of Electrical Engineers*, vol. 64, p. 803.

(iii) Per square mile.
(iv) Per mile of route of the electrical distribution line.

Of these methods the first is useful in making a general survey, the number of electrical units of energy consumed per annum per head of population being an index of general progress of electrification in the area considered. This obviously takes into account the number of premises connected to the supply, as well as the annual consumption per consumer.

The second method gives more detailed information for the benefit of the supply engineer, since the annual consumption per consumer gives a guide as to the revenue which may be obtainable in comparison with the cost of giving a supply to the consumer.

An assessment based on the consumption per square mile must, of necessity, be very indefinite, since any given square mile of country varies in character, and in the number and potentialities of consumers, from almost every other square mile. An average figure of consumption per square mile would give little indication, therefore, of that which might be obtainable in any particular case.

The last method of assessment, per mile of route of the electric lines, gives very useful information to a supply engineer, since it gives a figure showing the possible revenue as compared with the capital expenditure, which is largely proportional to the length of the distribution line. Such a figure must depend, however, upon the layout of the line in relation to the area served by it. This layout must be influenced, in many cases, by considerations other than those of supplying the maximum number and size of consumers per mile of route, although the latter consideration is naturally a very important one.

Since interesting information is available under each of these four headings, it might be well to utilize them, especially as there can be no one method of assessment of demand which is ideal from all points of view.

(i) Demand per Head of Population

This method of estimating demand was used in the Electricity Commissioners' Report on Rural Electrification previously mentioned. Appendices to this report analyse the consumption of electricity in 567 townships or villages in England and Wales having a total population of 1,052,207. The average annual consumption per head of population for these townships was 74 units, but it is shown that in 404 of these the average annual consumption per head was only 16 units. Of the remainder, in 75 cases the average was 69 units, and in 56 cases 171 units. The explanation of these large differences in consumption lies in the fact that some townships were situated on the fringe of industrial areas, the consumption in these being considerably higher than that in townships remote from such areas. A number of townships contained factories or other large power consumers, and this increased the average consumption per head of population very greatly. To emphasize this last point, an example of 11 townships in England and Wales is taken, the total population of about 37,000 consuming annually about 7,900,000 units, of which about 7,380,000 units were taken by large power consumers. This means an average annual consumption per head of only 15 units, excluding the large power consumers, as against an average of 214 units if these are included.

The conclusions reached in the report are that, excluding large power consumers, the development after three or four years from the commencement of the supply, assuming a progressive policy and suitable tariff to be adopted by the supply authority, together with appropriate publicity and hire-purchase arrangements, should be as follows :

(*a*) In the case of rural areas of a suburban character or surrounding urban areas .	60 units per head per annum.
(*b*) In the case of the next surrounding belts of purely rural territory	30 to 40 units per head per annum.

On such a basis the total demand in the course of the next few years is estimated at 230 million units per annum for rural small power consumers in areas where electricity supply powers already existed (in 1927). It is pointed out, however, that such an estimate " can only be regarded as of a tentative character."

Now, it must be remembered that these estimates were based upon records of consumption in rural areas which had, in many cases, received a supply for only a short time. Since most new consumers start by taking a supply for lighting only, the domestic power load being a gradual development, it is probable that the figures quoted were based on what was very largely a lighting load. Since 1927, rural electrification has attracted sufficient attention for the supply powers to be extended very considerably ; thus, in 1927 electricity supplies were authorized in 59·8 per cent. of the area of rural England and Wales, this area covering 77 per cent. of the rural population. While at the present time almost the whole of the rural area, with the exception of the north and north-western districts of Scotland, is included in the "occupied" area (i.e. the area for which supplies have been authorized), such areas now include more than 99 per cent. of the population of Great Britain. Again, during the last few years the developments in connection with electric cooking and heating have been very great, so that, while even so recently as five or six years ago the prospect of any appreciable amount of electric cooking in rural districts appeared remote, it is now commoner in some rural districts than it is in towns, owing to the competition of gas cookers in the latter. In mid-Cheshire, for example, where the electricity tariff for rural districts is such as to encourage the installation of cookers and electric water heaters, the author visited about a dozen medium-sized houses and farms in one parish in which such cookers had been installed within a few months last summer. That this does not apply to one district alone is shown by the fact that it is stated, in the Annual Report of the Electricity Commissioners for 1933–4, that in the Bedford Rural Area, in the case of 4,075 domestic and farm consumers the electrical installation included 1,239 electric cookers, 104 electric wash boilers, and 72 electric water heaters, while in the Norwich area, in the case of 1,977 consumers of the same type, 373 electric cookers were installed, the load connected for heating and cooking purposes being 2,648 kilowatts out of a total connected load of 3,576 kilowatts.

As an example of the increase in consumption per head of population during recent years, we will consider the Chester rural supply area. In 1928 the area consisted of 60·4 square miles, having a population of 15,319, the annual consumption per head being then 48·9 units.[1] In 1932 the area had been extended to 138 square miles, having a population of 27,848, and the consumption per head was 133 units.[2] Now, while this area, surrounding the city of Chester, is admittedly somewhat favourably situated as regards electricity supply, more than half of the consumers were connected to the supply between 1928 and 1932, so that the annual consumption per head of population shows a very considerable advance upon the figure of 60 units per head already mentioned for rural areas surrounding an urban area with which the Chester area is comparable.

From the above facts, it would appear that the estimate of a total consumption by rural domestic and small power consumers of 230 million units per annum made in 1927 is much too small to apply to the development which might be expected during the next few years.

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[1] *Electricity Commission Report on Electricity Supply in Rural Areas* (1928).

[2] *Five Years' Progress in the Electrification of Agriculture around Chester*, by S. E. Britton, published by the British Electrical Development Association.

(ii) Demand per Consumer

The basis of annual demand per consumer was chosen by Messrs. E. W. Dickinson and H. W. Grimmitt in their paper on "The Design of a Distribution System in a Rural Area."[1] (This paper, and also the reports of the discussions of it, provide a very valuable survey of the question of rural electrification from the point of view of the electrical engineer.) One of the most important statements in the paper is that "the amount of electricity taken by the consumer has a definite relationship to the price charged." From the consideration of the results of 221 authorized undertakings giving rural supplies in 1929–30, the authors show that the units sold per consumer increase as the price per unit falls, and at the same time the total revenue from each consumer increases with increasing consumption. The formula

$$\text{Cost per unit (pence)} = \frac{1{,}140}{\text{units sold per consumer}} + 0{\cdot}73$$

is obtained from these results. As an example of the use of this formula, if the average consumption is 2,280 units per annum, the corresponding revenue per unit is:

$$\frac{1{,}140}{2{,}280} + 0{\cdot}73 = 1\tfrac{1}{4}d. \text{ (approx.).}$$

In the discussion following the paper, Mr. R. W. L. Phillips made the statement that "a reduction in the tariff is accompanied not only by an increase in revenue, but also nearly always by larger gross profits," and gave figures relating to his own supply system (Bedford) illustrating this.

When a supply is given for lighting only, the annual demand in the case of domestic premises is too small for the above rule to apply. The tariff in such cases is usually a flat rate of from 6*d.* to 1*s.* per unit, and the annual demand is from 50 to about 500 units, according to the size of house. If electric heating and cooking are adopted, the annual demand rises to from about 1,200 to 6,000 units, according to the size of house, and, as pointed out above, to the tariff under which the electricity supply is given.

Although costs of electricity in detail are not under discussion in this chapter, it is of interest to note that in the paper referred to above the estimated revenue to be obtained by electricity supply undertakings at the commencement of the supply varies from £2 10*s*. to £3 10*s*. per annum for small cottages to £20 to £30 per annum in the case of large residences, most of the intermediate figures, for farms, villas, public houses, etc., being about £5 to £8 per annum. Over the same range, what is called the " saturation revenue," based upon the cost of supplying electrically all the heat and light at present derived from paraffin, coal, wood, etc., varies from £8 to £10 per annum to £50 to £100 per annum. Although it may not be realized, without an actual calculation of the costs of heating and lighting by non-electrical means, it will be found that these estimated costs are not, by comparison, excessive.

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[1] *Journal of the Institution of Electrical Engineers*, vol. 70, p. 189.

From an investigation made by the Electricity Commissioners in 1930, it was discovered that the average annual consumption in rural areas was then 1,163 units for farms and 432 units for domestic consumers. These figures indicate that little energy was being used for power purposes on farms, and that the majority of domestic consumers were using electricity for lighting only. The developments in heating and cooking apparatus, the introduction of hire-purchase schemes, and the adoption of a suitable two-part tariff should have the effect of increasing these consumptions in the future, especially if it is borne in mind that many consumers had not then been receiving a supply for a sufficiently long period for their normal consumption to have been reached.

In rural districts in England and Wales there are, on an average, 4·4 persons per inhabited dwelling. Hence, if *all* the dwellings were connected to the electricity supply, the average annual consumption per consumer would be 4·4 times the annual consumption per head of population for any given district, neglecting any industrial or large power consumers and such consumers as churches, institutes, etc., which cannot be classed as inhabited dwellings. Taking such consumers into account, the annual consumption per consumer is less than 4·4 times that per head of population (assuming all dwellings to take a supply).

A simple example may be useful to show the effect of consumers other than occupied houses. Thus, suppose that in a village there are 50 houses having an average of 4·4 persons per house, all the houses being connected to the supply, then, for a consumption of 100 units per head of population the total annual consumption is :

$$50 \times 4{\cdot}4 \times 100 = 22{,}000 \text{ units.}$$

Per consumer the annual consumption is $\frac{22{,}000}{50} = 440$ units.

$$\text{The ratio } \frac{\text{Consumption per consumer}}{\text{Consumption per head}} = \frac{440}{100} = 4{\cdot}4.$$

If, now, five additional consumers (not inhabited dwellings) are connected, each having an annual consumption of 1,000 units, we have a total annual consumption of 22,000 + 5,000 = 27,000 units.

$$\text{Consumption per head of population} = \frac{27{,}000}{50 \times 4{\cdot}4} = 123 \text{ units.}$$

$$\text{Consumption per consumer} = \frac{27{,}000}{55} = 490 \text{ units.}$$

$$\text{Ratio} = \frac{\text{Consumption per consumer}}{\text{Consumption per head}} = \frac{490}{123} = 3{\cdot}98.$$

Thus the ratio has been reduced from 4·4 to 3·98.

Again, if only half of the inhabited dwellings are connected to the supply, for a consumption of 123 units per head of total population the total consumption is, as before, 27,000 units. The consumption per consumer must now increase to $\frac{27{,}000}{30}$ = 900 units, and the ratio to $\frac{900}{123} = 7{\cdot}3$. The effect of a reduced proportion of the total premises being connected to the supply is, obviously, to increase the consumption per consumer for a given consumption per head of population.

In connection with the rate of connection of consumers when electricity is made available in any particular district, Dickinson and Grimmitt [1] give a graph showing the estimated percentage of the total occupied dwellings which may be receiving a supply at various dates after that upon which the supply is first made available. They estimate that this percentage should rise from about 20 per cent. six months after the commencement of the supply to about 75 per cent. five or six years later. As this rate of connection must depend upon so many variable factors, such as the existence of a gas supply in the district, the availability of assisted wiring schemes, the electricity tariff adopted, the energy and initiative of the supply engineer, and so on, it is difficult to dispute or, in general, confirm these estimates. That they are not unduly optimistic is indicated, however, by the data given by various speakers in the discussions on the paper in different parts of the country. Thus, one speaker mentioned a village in his district in which 63 houses out of 80 were connected to the supply, in four months. Another speaker, illustrating the effect of a deferred-payment wiring scheme, instanced a village in which, before the introduction of the scheme, 50 per cent. of the houses were connected in the first seven years of supply, while after its introduction all the remaining houses were connected in the next two years or so.

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[1] *Loc. cit.*

(iii) **Annual Consumption per Square Mile**

The consumption of electricity per square mile is, of course, intimately connected with the density of population. It was shown in Table I, p. 9, that for rural areas in England and Wales the average density of population is 154 per square mile. It is perhaps fortunate, from the point of view of electricity supply, that this density is not uniform throughout the country. Thus, the density in areas adjacent to urban districts is usually considerably greater than this, while even in the more sparsely populated districts remote from the towns any particular square mile may contain the whole or part of a village in which the density of population is much greater than the average for the surrounding neighbourhood. Electricity supply is thus more likely to be economically possible than if the population was scattered more or less uniformly over the whole area. Again, a supply having been given to such a village, it may be found possible to run lines, off-shooting from the main distribution lines, to supply certain outlying consumers if their potential demand is great enough.

A summary of rural electrification in England up to March 1930 given by Dickinson and Grimmitt shows that at that date the areas over which distribution powers were authorized had an average density of population of 178 per square mile, while in areas in which low-tension distribution lines had actually been laid, the density was 370. In areas where there were then no powers of distribution, the density was only 88 per square mile. As might have been expected, this shows that distribution powers had been applied for and granted in the case of the more populous districts of the country, while of these the more densely populated parts had been developed first.

The total population in those parts of England for which no distribution powers were then authorized was only about 970,000, or rather less than 14 per cent. of the total rural population. As regards the undeveloped area, it is stated, in the Electricity Commission Report on Rural Electrification (1928), that " there is no doubt that the prospects in the sparsest and most remote areas are of such a low order as to preclude, or at any rate delay for many years to come, the establishment of a public supply on a remunerative basis, even under the most favourable conditions of capital expenditure on rural distribution. It has been variously estimated that up to 50 per cent. of the more sparsely populated rural portions of the country is likely to fall within this category." There were, however, in 1930 some 27,000 square miles of rural England, having an average density of population of 126 per square mile, for which distribution powers had been granted, but in which no distribution mains had actually been laid. It is this area, for which an electricity supply though requiring careful consideration and planning is not economically impossible, which awaits development.

In some discussions of rural electrification, parishes have been considered instead of the undistinguished area in square miles. In England and Wales there are 12,926 parishes in rural districts, and the average area of these is 4 square miles, so that most of them will contain a village or other collection of houses where the density of population is above the average. Of these parishes 34·4 per cent. were not included in areas for which electricity supplies were authorized in 1928, but of such parishes 77 per cent. had an individual population of less than 500. The number of farms in England and Wales of over 100 acres extent in 1933 was 78,697 in a total rural area of approximately 52,000 square miles. This means an average of 1·5 such farms per square mile, or 6 per parish.

Even the parish is too small a unit to be used in the general discussion of the possibilities of electrification, and perhaps the best method of arriving at an estimate of demand in an area is one similar to that adopted by Dickinson and Grimmitt in the paper already mentioned. In this paper an area of about 400 square miles, which the authors consider to be the minimum size for a complete electrification scheme, is considered. It is referred to as a " model " scheme, and is purely imaginary in the sense that it does not refer to any particular area in the country, but in respect of the number and potential consumption of consumers, and in all respects so far as electrification is concerned, it represents the average conditions for the rural districts as a whole. The actual size of the rural area for which full information is given in the paper is 384 square miles,[1] containing 96 parishes (reckoning 4 square miles per parish). A density of population in the area of 150 per square mile is assumed, which, at 4·4 persons per inhabited dwelling, means 34 such dwellings per square mile, and hence a total for the area of 13,056 dwellings. The 96 parishes in the area are divided as to size in the same proportions as such sizes occur in the analysis of all the parishes in England and Wales, and their average populations are adjusted to give a density of 150 per square mile, as shown in the following table :

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[1] Sixteen square miles of the 400 being assumed to be urban area.

TABLE XIV

Scale of population of parishes.	Number in the model scheme.	Average population per parish to give a density of 150.
Up to 100	16	60
101 to 250	28	210
251 to 500	24	450
501 to 750	12	720
751 to 1,000	4	1,000
1,001 to 2,000	8	1,800
Above 2,000	4	3,000

It is assumed that there is one village per parish and four isolated large consumers (farms, institutions, etc.), together with an industrial load, which is assumed to be 50 per cent. of the total load in the area. It is pointed out that in designing the electrical equipment for the area it should be assumed that 90 per cent. of the premises in the area will eventually be connected to the supply. The percentage of the total premises connected to the supply at the end of six years is estimated at 73 per cent., and the full estimates for the sixth year read as follows :

Total number of consumers	9,530 (73 per cent. of 13,056)
Units sold per consumer per annum :	
Domestic	1,000
Power	750
Total	1,750
Total units sold per annum	16,678,000
Load factor	23 per cent.

Hence, the estimated consumption of electricity per square mile, based on the figures given in connection with this model scheme, is 43,400 units, although such a figure has little significance unless the area to which it refers is taken into account.

(iv) Annual Consumption per Mile of Route of the Distribution Lines

The following facts are important in considering the consumption per mile of route of the distribution lines : first, the total costs of construction and erection of low-tension distribution lines is between £400 and £600 per mile, according to the size of conductor used, while for high-tension (11,000-volt) lines, the cost is from £350 to £650 per mile. Second, the total capital costs in connection with electricity supply in a rural area usually amount to from £2 10*s*. to £4 per head of population, of which rather more than half is on account of transmission and distribution. Again, for remunerative working the annual revenue derived from this supply should be at least 20 per cent. of the capital costs, i.e. 10*s*. to 16*s*. per head of population. It is very necessary, therefore, that the number of consumers and annual consumption per mile shall be as large as possible.

Mr. R. B. Matthews [1] has given figures as follows for the annual consumption of electricity per mile of route in rural districts :

	Units.
For lighting, cooking, heating, and barn work on farms .	10,500–22,500
For rural industries and lighting	4,000– 8,000
Total (without ploughing)	14,500–30,500

Data regarding Consumption of Electricity in Various Districts

The information given below (Table XV) is not intended as in any sense a complete survey of existing conditions, but rather as examples from actual practice confirming to some extent what has been stated in preceding paragraphs regarding the consumption of electricity in rural districts. In none of the cases quoted has the district concerned become fully electrified (see column 3). In all cases the supplies have been available for too short a time for complete electrification to have been attained by normal development. Again, in column 6 the figures for annual consumption per consumer are lower than the true figures for such consumption, owing to the basis of consumers connected at the end of the year. The rapid increase in the number of consumers in these districts means that a considerable proportion of the total number of consumers received a supply for only a portion of the year under review.

The areas in the table are all sufficiently large for the figures obtained to be free from the exaggeration which is possible when very small and specially favoured areas are considered, and it must be admitted that the results indicated are far from discouraging.

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[1] *Journal of the Institution of Electrical Engineers*, vol. 64, p. 802.

TABLE XV

EXAMPLES OF ANNUAL CONSUMPTION OF ELECTRICITY IN RURAL DISTRICTS

(1) Area of supply.	(2) Approximate date to which information applies.	(3) Percentage of total premises connected to supply.	(4) Total annual consumption (approx.) (Units).	(5) Number of consumers at end of year.	(6) Annual consumption per consumer (based on consumers at the end of the year.) (Units.)	(7) Average revenue per consumer.	(8) Annual consumption per head of population. (Units.)	(9) Density of population (per square mile).	(10) Annual consumption (per square mile). (Units.)	(11) Annual consumption per mile of route of transmission and distribution lines. (Units.)	(12) Source of information.
Chester (Rural Area)	1933	49	3,700,000	Total 3,015 Farms 300	1,227 1,932	£7 0*s.* £16 13*s.*	133	202	26,800	19,576	Mr. S. E. Britton, B.E.D.A. publication No. E.D.A., 1179.
Chester (Rural Area)	1935	69	5,074,000	Total 4,297 Farms 510	1,181 3,133	£6 15*s.* £18 2*s.*	182	202	36,767	22,958	Mr. S. E. Britton, Engineer & Manager, Electricity Dept., Chester.
Bedford	1933–4 (4th year of supply)	67	5,200,000	Total 4,087 Farms 202 Domestic 3,873	1,270 1,320 560	£5 10*s.* £8 2*s.* £3 17*s.*	270, or, excluding large power consumers, 127	176	47,700, or, excluding large power consumers, 22,400	23,800, or, excluding large power consumers, 11,200	*Electricity Commissioners' Fourteenth Annual Report.*
Norwich	1933–4 (3rd year of supply)	51	820,000	Total 1,982 Farms 157 Domestic 1,820	415 590 362	£3 12*s.* £4 16*s.* £3 8*s.*	60, or, excluding large power consumers, 55	110	6,560, or, excluding large power consumers, 6,000	4,970, or, excluding large power consumers, 4,550	Ditto.
Aylesbury	1931 (5th year of supply)	—	4,800,000	4,692	Total, 1,020 Farms, domestic, and small consumers 490 (approx.)	£7 13*s.* £6 4*s.*	109 52	191	Total, 20,800 Farms, domestic, and small consumers 10,000	23,800 11,400	Mr. W. A. Turnbull, *Journ. I.E.E.*, vol. 70, p. 255.
Dumfriesshire	1936 (3rd year of supply)	41	5,813,000	Total 6,290 Farms, over 431	925 1505	£7 4 £11 8	100	54	5,500	9,250	Mr. J. S. Pickles, County Electrical Engineer, Dumfriesshire.

CHAPTER IV

DEVELOPMENT OF RURAL ELECTRIFICATION—THE PRESENT SITUATION

IN preceding chapters we have discussed the importance of the agricultural industry in this country and its power requirements, and have arrived at the conclusions that increased mechanization of farming would be beneficial, that whatever the size or type of farm, a proportion of this increased mechanization might profitably be in the form of electrically driven equipment, and that the total annual consumption of electricity on farms and in rural districts would reach a very large figure in a few years if full advantage were taken of the availability of a supply. The most recent figures regarding electrification in rural districts show that, of the total rural area of 51,800 square miles in England and Wales, electricity supply powers have been granted for approximately 49,985 square miles, this area having a population of 7,856,675.[1] The population in the " unoccupied " rural areas is 143,090 (i.e. 1·8 per cent. of the rural population).

These figures do not mean, however, that electricity is actually available to some 98 per cent. of the rural inhabitants, since low-tension distribution lines, which are necessary for supplies to individual consumers, are not yet laid in the whole of the so-called " occupied " areas. The most recent information available as regards the extent of these low-tension lines refers to 1930. The approximate area of parishes in England and Wales, in which such lines were then laid, was 8,000 square miles, having a population of some 3 millions. This area naturally included the more populous rural districts. Even though we assume this area to have been doubled by developments during the last five years[2] there still remains more than 30,000 square miles of rural area in which there are no low-tension distribution lines, although electricity supply powers have been granted. The rural population still awaiting a supply of electricity may be estimated as between 3 and 4 millions. To arrive at the approximate number of potential rural consumers, we may take the figure of 3½ millions of population which, at 4·4 inhabitants per dwelling, gives almost 800,000 potential consumers in the form of occupied dwellings alone, apart from the miscellaneous consumers which cannot be so classed.

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[1] These figures were kindly supplied to the author by the Electricity Commissioners.

[2] That rapid progress is being made is indicated by the fact that about 9,300 miles of low-voltage distribution mains were provided in rural areas in the five years ending March 31st, 1934.

Of the 388,433 farms and agricultural holdings in England and Wales, the number connected to electricity supplies at present has been variously estimated at from 8,000 to 25,000. It is difficult to obtain exact figures for the number of such farms, but an investigation by the Electricity Commissioners in 1930 showed that of the total rural consumers 2,485 were classed as farms, and it is certain that with the progress made in the last few years the present number considerably exceeds this.

Future Prospects

Now, from data given in Chapter III for existing rural electrification schemes, some of which cover areas having a density of population about equal to, or even less than, the average for the whole rural area of the country, it can be seen that such electrification is an economic possibility, in spite of the difficulties and heavy costs of supplying such rural districts. Again, the paper by Dickinson and Grimmitt already referred to shows, from very carefully estimated figures of expenditure and revenue for rural areas having different densities of population, that the extension of a supply to the at present unelectrified districts would be " a practical proposition from a technical and financial aspect," assuming that a suitable tariff for electricity were adopted, together with adequate publicity and suitable methods of development. It is shown that if the whole of the remaining rural area were electrified, the scheme should be self-supporting at the end of six years, the estimation being upon the basis of results achieved in already electrified areas and upon the annual consumption obtained when the charge for electricity is adjusted to encourage consumption by a reduction in the price per unit as the consumption increases.

Taking a figure for the required capital expenditure of about £35 per consumer the electrification of the remaining rural districts would involve an expenditure of some £30 millions in providing the supply, apart from the capital required for consumers' wiring and electrical equipment, which would be more than equal to that for the provision of the supply. This capital would be spent with electrical manufacturing and contracting firms in this country, and would be a very useful stimulant to trade, involving the absorption of a large amount of labour. Again, in the sixth year this electrification would necessitate the use of an additional million tons or so of coal, annually, in the generating stations, and would reduce the annual imports of paraffin to this country by several millions sterling.

From these facts it appears evident that, as the authors of the paper mentioned conclude, " no adequate reasons are apparent why electrification should not, in areas over which powers of supply are held and are not yet electrified, be proceeded with at once."

Interdependence of Rural Consumers and Supply Undertakings

The reader may wonder why, if it can be shown that rural electrification is commercially possible, from the point of view of the electricity supply undertaking, at a price for electricity which the rural consumer would be prepared to pay, such electrification is not being carried out as quickly as possible. It is difficult to answer such a question with any precision, but the author feels that it may be due to a lack of mutual understanding, and, to some extent, a lack of appreciation of the possibilities by rural consumers and by some supply undertakings.

Considering first the rural consumer, it may appear to the non-technical man to be a simple matter, especially if he is situated near to the National Grid lines, for the supply authority to connect his premises directly to these lines and to give him a supply at a charge of (say) 1*d.* per unit, regardless of the amount of electricity which he may use. For the benefit of the non-technical reader, a brief statement of some of the reasons why such a procedure is impossible may be made. These are as follows :

(i) In order to avoid the very large losses of power which would otherwise occur in a long-distance transmission system, such as the National Grid, it is necessary to operate these lines at a very high electrical pressure (or "voltage "). The pressure used is 132,000 volts [1] as against pressures of only 230 volts or 400 volts which are commonly required for consumers' lighting and power. For reasons of safety, apart altogether from the many technical reasons why such direct connection would be very undesirable, it would be quite impossible to bring lines carrying this high voltage into a consumer's premises. The voltage can be reduced to the consumer's voltage of 200 to 400 volts by means of pieces of apparatus called "transformers," but the cost of such transformation of voltage, together with the necessary switchgear for tapping the Grid lines, would cost something of the order of £20,000 to £30,000 per tapping. The number of such tapping points has to be reduced, therefore, to one or two for a whole supply area. At these points the voltage is transformed down to 33,000 or 11,000 volts, and lines operated at this pressure are run over the district to supply, through more step-down transformers, still lower-voltage lines operating at 230 or 400 volts, to which the consumers are connected.

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[1] The " volt " is the unit of electrical pressure (see p. 91).

(ii) In addition to the costs involved in the provision of the transmission and distribution lines and transformers necessary to supply the required voltage at the consumer's premises there are other expenses, some of which are less obvious to the non-technical observer. There are, for example, the expenses incurred in obtaining wayleaves for the overhead lines, and in compensation for damage to property and inconvenience caused to the owners of the land over which the lines pass. (Incidentally, the excessive demands for compensation which are sometimes made in this connection is a factor which tends to increase the cost of electricity to the rural consumer and indicates a lack of co-operation on the part of some rural inhabitants in furthering electrification schemes.) Again, overhead electric lines have to comply with a rigorous code of regulations set up for the safety of the public. The provision of poles high enough to give the required minimum height above ground and of suitable protection at road crossings lead to considerable expense. The voltage at the consumer's premises must, according to the regulations, be maintained at the declared voltage within narrow limits, and this necessitates the provision of additional apparatus on account of the varying pressure drop in the lines from the point of supply to the consumer.

The above statements may explain the necessity for a capital expenditure, on the part of the supply authority, of something of the order of £30 to £40 per consumer. On this basis the annual capital charges (interest and depreciation) amount to about £2 10*s*. to £3 per consumer. Management, rates and taxes, and other annual expenses, exclusive of the cost of the actual electricity sold, amount to about £1 5*s*. to £1 10*s*. per consumer, so that there are on an average annual expenses of about £4 on behalf of each consumer merely in connection with the provision of a supply, regardless of whether the actual consumption is large or small. In fairness to the supply undertaking, it is clear that this annual charge must be recovered by the adoption of a method of charging for electricity which ensures that at least a portion of this is paid by the consumer as a fixed charge, together with which there must, of course, be a charge which is proportional to the actual consumption. The latter charge (per unit consumed) is usually fairly small, and so it happens that although the annual account for electricity in the case of the small consumer will, on account of the fixed charge, represent a fairly high charge per unit consumed, in the case of the large consumer the fixed charge forms only a small part of his total bill, and the price per unit consumed approaches more nearly to the small unit charge.

The above facts may serve to make clear the difficulty of guaranteeing an electricity supply at a small uniform charge per unit regardless of the probable consumption. If the potential consumer had the ability to pay for a considerable annual consumption such a guarantee might be a wise procedure, provided the provision of a supply were followed by demonstrations as to the uses to which it might be put and, possibly, by suggestions as to hire-purchase arrangements to enable the consumer to install apparatus which would increase his consumption to a value sufficient to be profitable to the supply authority.

These last points lead us to the consideration of the part to be played by the supply engineer in developing the rural load. It is obvious that his responsibility does not end with the construction of a cheap and efficient network for the supply of his district. The building up of the load is part of his function. Assuming that the distribution system has been designed to be capable of dealing with possible future developments of load, the cost to the supply authority of providing a consumer with double or treble his initial consumption is, owing to the fixed capital charges mentioned above, far less than proportional to the increased consumption, so that it is to the advantage of the supplier that such an increase shall be brought about.

Now, there is no doubt, from past experience, that the consumption of most consumers—unless it be for lighting purposes only—does increase with time, provided the electricity tariff is suitable, but the rate of increase is likely to be slow in rural districts unless methods of accelerating it are adopted. The difference between rural and urban consumers in the matter of installation of power-consuming electrical devices is not always sufficiently appreciated. The urban consumer has many opportunities of becoming familiar with such devices, which are denied to the rural inhabitant. In the case of many farmers, for example, their infrequent visits to the local towns are often fully taken up with essential business in connection with the sale of their produce or the purchase of stock and little time is left for becoming acquainted with the latest electrical devices. This applies to such common domestic equipment as electric fires, cookers, water heaters, etc. When electrically operated agricultural equipment is considered, the difficulty is still greater, since such equipment is very seldom there to be seen, even if the time were available.

Displays at the showrooms of the local electricity supply company and at agricultural shows undoubtedly serve a useful purpose, but in the author's opinion these are insufficient. Any method which involves a visit on the part of the farmer for inspection purposes is likely to be far less successful than the method of taking suitable equipment to his premises, so that he can note its performance on the spot. A number of supply companies have fitted up and used demonstration vans for this purpose, and it seems that these could, and should, be more widely adopted. Too often a farmer who is taking a supply for lighting and small domestic uses is left in almost complete ignorance as to the many electrical devices which are available for farm work, some of which would certainly be profitable to him. It is surely in the interest of the supply authority that the farmer should be made acquainted with such equipment and with the exact costs of installing and running it ; and it is difficult for him to discover the details himself without the assistance of the engineer. Of course, one must admit that such an active publicity campaign demands both capital expenditure and considerable effort on the part of the supply engineer, who has already so many demands upon his time and energy, but it seems to be the only way to develop the load satisfactorily.

Another difficulty at the present time is that the present number of electrified farms in the country is insufficient to justify more than a small amount of attention and of advertising on the part of manufacturers of agricultural machinery and equipment. To take a small example of this, the writer saw recently, in a large shop, a window display of a number of different designs of brooders and similar equipment for poultry-farm work, all of which were heated by paraffin lamps, although this is one purpose for which electricity is particularly suited, and there are on the market several well-designed and successful electrically heated forms of this equipment. While it might appear unreasonable to take one isolated example, it is certainly evidence in support of the statements made above. This state of affairs will, however, change in the normal course of development during the next few years as the number of electrified farms increases.

While the above remarks apply more especially to consumers who are already connected to the supply, similar activity is necessary in obtaining additional consumers. One of the most successful methods adopted has been the assisted- or deferred-payment wiring scheme, which relieves the consumer of the large initial outlay on the electric wiring for his premises. The schemes adopted by different supply authorities have varied in detail, but in almost all cases they have been found to accelerate the rate of connection to the supply very considerably.

Again, personal contact between the supply authority and the potential consumer is necessary in obtaining rural consumers, and it is essential also in the case of farmers, many of whom are only tenants of the farms they occupy, that the risk of loss on expenditure on electric wiring and equipment shall be obviated in the event of the farmer terminating his tenancy.

Developments in Other Countries

Before concluding this brief survey of the situation as regards rural and agricultural electrification, a few notes will be given on developments abroad. The information available is by no means complete, but these notes may be useful by way of comparison with our own state of development.

New Zealand.—The subject of rural electrification in the Dominion of New Zealand is particularly interesting on account of the very high degree of electrification which has been attained in comparatively few years in a country which is very largely agricultural and in which the average density of population, including the towns, is only about 13 per square mile. The agriculture is principally pastoral in character, 88 per cent. of the cultivated land being under grass, and there are few industries to take large blocks of power from an electricity supply system. There is, however, an abundant supply of water power, and this is used for the generation of electricity, some 98·4 per cent. of the total output of electricity being so generated in the year 1932–3. On the other hand, water-power schemes are almost always expensive as regards initial capital cost, and great difficulties have been experienced in the construction of transmission lines owing to the wild character of certain parts of the country.

Electricity is now available in some 21,000 square miles, rather more than 20 per cent. of the total area. The electrified area includes, however, about 93 per cent. of the total population, 56 per cent. of whom live in urban areas. In the areas of supply the average density of population, including the urban areas, is only 70 per square mile, and the average number of consumers 15 per square mile. All the loads supplied are comparatively small, except one of 3,000 kW. The development has thus been chiefly on the domestic and agricultural side.

Within the area of supply the consumption per head of population has risen from about 140 units per annum in 1920 to the very high figure of 452 units in 1932–3. The total capital invested by public supply companies (including £12 millions on Government schemes) is £32½ millions. It is interesting to learn that, since their inception in 1915, the various Government electric power schemes have paid all operating charges and interest on borrowed capital and have earned an additional £820,000, which has been allotted to various reserve funds. Details regarding the supply are given below in tabular form :

Capital expenditure per consumer	£100 (approx.)
Total route-miles of transmission lines	20,585
Total number of consumers (March 1934)	334,000
Consumers per mile of route	16 (approx.)
Revenue per mile of route	£180
Revenue per mile (rural areas only)	£40 to £50
Average revenue per consumer	£11 (approx.)
Average revenue per unit for all purposes	1·28*d.*
Average cost per unit	1·143*d.*
Installed capacity per head of population	0·24 kVA (approx.)
Average annual consumption per consumer for all purposes	1,970 units
Number of electric cookers installed	36,000 (approx.)
Number of electric water heaters installed	50,000 (approx.)
Number of electric milking machines installed	17,000 (approx.)

The average cost per mile for an 11,000-volt 3-phase transmission line is £220, this comparatively low figure being partly due to the facts that there are no wayleave difficulties and no question of priority rights on the part of the Post Office authorities. A high load factor of between 40 and 50 per cent. is obtained, this being explained by the fact that the peak loads in the rural districts—largely due to the milking-machine load—occur at different times from those in the urban areas, and to the use of time switches in connection with domestic electric hot-water systems, for which cheap night rates are available.

Distribution in New Zealand is largely (though not entirely) carried out by a number of Power Boards, each of which is responsible for the supply in a particular area. These areas usually consist of an inner, more densely populated, area, together with an adjacent sparsely populated district. A Power-Board area is constituted as a result of a petition signed by at least 25 per cent. of the ratepayers in the area, and the Board has various rating powers as security for the capital borrowed for the electric development of the district. It has not been found necessary, however, to use these rating powers to any considerable extent except as security for the capital.

Much of the above information has been obtained from a paper by F. T. M. Kissel, entitled: "The Organization of Electricity Supply in New Zealand" (*Journal of the Institution of Electrical Engineers*, vol. 77, p. 63, July 1935). This paper gives a very full account of the progress made in and the administration of electricity supply in New Zealand.

France.—More than 80 per cent. of the communes in France have an electricity supply. Before the war rural distribution was undertaken by Agricultural Co-operative Societies. Of recent years the French Government has adopted a policy of encouraging rural electrification as much as possible with the object of checking the movement of labour from the land. A Department of Rural Engineers has been formed to undertake electrification schemes financed wholly or partly by the Government. More than 25,000 rural communes have received financial assistance for this purpose, the total sum granted by the Government being about £15 millions.

In some districts wayleave difficulties have been overcome by running distribution lines along the roadways, a small fee per kilometre being paid to the rural or road authority. Regulations regarding the distribution and use of electricity are less rigorous than in this country. Portable transformer wagons are used for the purpose of tapping high-voltage lines, cheap and quickly erected temporary lines being run from the transformer for a supply to machines for field work. In some cases a supply at several thousand volts is used for machines in the field, but one has little hesitation in pronouncing this a dangerous practice.

In addition to the use of electricity for irrigation pumping, an appreciable amount of electric ploughing has been carried out during recent years. In the district surrounding Paris, contract ploughing is undertaken by a special company formed by, and working in conjunction with, various electricity supply authorities. Small ploughing equipments, driven by electric motors of as little as 7½ h.p., have been used on vineyards and small-holdings.

Germany.—Agricultural electrification is in an advanced state in Germany, about 80 per cent. of the farms being supplied with electricity. More than a million electric motors are in use on German farms, over 90 per cent. of the power units installed being electrically operated. The German Government, in recent years, has adopted a policy of dividing up a number of large estates, which have come into the market, into small agricultural holdings for occupation by the unemployed. From 10,000 to 20,000 of such holdings have now been created, and most of these are equipped with electricity. A very large number of small motors, specially designed by German manufacturing firms to suit agricultural requirements, are in use, and the design of many German agricultural machines appears to have been modified to render them suitable to such motor drives. Threshing by electricity is common, and a small threshing machine, capable of being driven by a 1¼-h.p. motor, has been produced, obviously for the use of the small-holders who already possess cheap, low-powered electric motors for other farm purposes. The large number of electrified small-holdings has encouraged German manufacturers to study the requirements of such holdings, and provides evidence that suitable electrically driven equipment can be produced if there is a sufficiently large demand to render its development worth while.

A number of electric ploughing equipments are in use, and another rather unusual development is the electrically driven pumping equipment, or " rain-cannon," for watering small fields and market gardens. For transporting crops such as hay, straw, and grain, pneumatic conveyors driven by electric motors, some of which are as small as 5 h.p., have been introduced. These have been found to be very convenient, since the conveying tubes are light and easily movable.

In some parts of Germany rural distribution of electricity is undertaken by Agricultural or Rural Co-operative Societies, which purchase a supply in bulk from the supply companies and distribute and retail it to their members. Some 370 of such societies are now in existence. This, and the fact that pole and transformer spaces are often granted free by farmers and land-owners, have helped very considerably in furthering rural electrification. It is interesting to note that, as regards the cost of electricity, Germany is very little more favoured than ourselves, the average cost (in 1934) being only some 10 per cent. less than that in this country. Water power is available for the generation of less than 20 per cent. of the total electrical energy generated.

As long ago as 1926 Mr. R. Borlase Matthews [1] gave details of the electricity supply in 34 rural districts, in which the average annual consumption of electricity was 50 units per acre, consisting of 12·5 to 22·5 units per acre for lighting purposes and from 27·5 to 42 units per acre for power purposes, exclusive of ploughing.

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[1] *Journal of the Institution of Electrical Engineers*, vol. 64, p. 803.

Belgium.—Almost all the parishes in Belgium have an electricity supply and a very large percentage of rural houses have electric light.

Small farms use electricity for milking and for dairy purposes while some of the larger farms carry out their own milling work by means of electrically driven milling machines.

Holland.—Electricity for power and lighting is available for more than 90 per cent. of the population, and electric cookers and heaters are being used considerably in rural districts. Contract threshing is carried out electrically in some parts, and a number of the windmills have been replaced by 20-h.p. electric motors. In one bulb-growing district soil-heating by electricity has been used for several acres of bulbs. The average price of electricity in Holland is almost exactly the same as in this country, but a special cheap rate is available for agricultural purposes.

Denmark.—Electricity is used by over 90 per cent. of the farmers in Denmark,[1] development on the distribution side having been fostered by Agricultural Co-operative Societies. Portable threshing machines having 5 to 7½-h.p. motors are used on small farms, the larger threshing machines having 20- to 30-h.p. motors. The annual energy consumption on Danish farms has been stated by Mr. V. Faaborg Andersen, Secretary of the Danish Royal Electricity Commission, to average 6·8 units per acre for a whole district, the maximum consumption, including its use for milling machines, being 21·2 units per acre.

Sweden.—The number of electrified farms in Sweden is about 100,000, the distribution in several cases being in the hands of Farmers' Co-operative Societies, which purchase electricity in bulk from the supply companies. These societies usually carry out the distribution in areas of an average size of 5,000 or 6,000 acres.

Soil-heating has been adopted by market gardeners to a large extent in some parts of Sweden. In the Stockholm district a large night load is taken for this purpose, the price charged being about ½*d.* per unit.

In south Sweden a load factor of about 60 per cent. is obtained.

A Swedish demonstration farm, almost completely electrified, was described in the *A.S.E.A. Journal* for July 1934.

Norway.—Little information is available regarding rural electrification in Norway, but it has been stated by Mr. R. Borlase

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[1] *Rural Electrification and Electro-Farming*, October 1933, p. 151.

Matthews[1] that 92,500 farms have an electricity supply out of a total of 208,500 farms.

Switzerland.—Almost the whole of the population of Switzerland has an electricity supply, and this is applied to a large number of small-power purposes on the farms. The annual consumption per head of population in agricultural districts was stated some years ago to be some 50 units.

Italy.—Considerable attention is being paid to the electrification of agriculture in Italy, an official Commission having been set up to conduct investigations in seven different areas, totalling 16,200 acres. Electrically operated pumping and irrigation plants have been used very successfully, and efforts are being made to develop electric ploughing. A number of Agricultural Cooperative Societies exist, several of these going rather farther than similar societies in other countries in that they own and rent electro-agricultural equipment as well as distributing electricity.

One society—the Società Anonima per l'Elettro-agricoltura—owns a number of electric ploughing equipments, and has ploughed thousands of acres annually as well as carrying out harrowing and threshing work. This company has cleared and cultivated a tract of sparsely wooded country of 24,700 acres, divided into a number of farms, a nineteen-mile 10-kV line being erected to feed an electric network for the purpose.

In other districts in Italy electricity is used for threshing as well as for a number of small-power purposes.

Russia.—The plans of the Soviet Government for the industrial development of Russia depend in very large measure upon the existence of an ample supply of cheap electricity. During the last twelve years, 56 large power stations and more than 8,000 miles of high-voltage transmission lines have been built.

In spite of the fact that many of these power stations have been used to supply the heavy manufacturing industries which it has obviously been considered most important to develop at the outset, a number of special agricultural stations and sub-stations have been built. In 1933 these stations generated 92 million units for agricultural work, and, according to the programme of development which has been drawn up, the number and capacity of the agricultural stations will be very greatly increased during the next few years.

Electric ploughing has been carried out in several parts of Russia for some years, some of the equipments having 80-h.p.

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[1] *Distribution*, January 1934.

motors. Electric threshing, also with very large sets, is carried out, over 2,000 electrically driven threshing machines being in operation in 1934. This number is rapidly increasing. There are also several large electrically operated irrigation systems, one of which has a capacity of 36 million gallons of water per day for a farm of 6,500 acres.[1]

United States of America.—From statistics published by the United States Department of Agriculture relating to the total energy consumption in American agriculture, it appears that some 5·4 per cent. of this is in the form of electricity as compared with 9·7 per cent. and 12·3 per cent. from petrol tractors and stationary engines respectively. More than 61 per cent. of the total energy used is in the form of animal power. These statistics support the statements which have frequently been made that the agricultural load has been developed in the United States to only a very small extent. The annual consumption of electricity for farm work was stated, however, by Mr. R. Borlase Matthews[2] in 1926 to be some 630 million units.

The agricultural load is being developed, it being estimated recently that a load of some 5,000 or 6,000 kilowatts and an annual consumption of between 4 and 5 million units have been built up for soil-heating purposes alone in market gardens and the like. Another development has been the use of electricity for the artificial drying of lucerne and grass, a number of large equipments for this purpose being in operation. Poultry farming is another branch of agriculture to which electricity is being successfully applied in America.

Canada.—Perhaps the most progressive part of the Dominion of Canada as regards rural electrification has been the province of Ontario. The Hydro-Electric Power Commission of Ontario, which is responsible for the generation of electricity at Niagara Falls and for its distribution to various local authorities, supplies more than 10,000 rural consumers in its area. To encourage rural electrification, the Government pays a considerable part of the cost of rural distribution lines. In 1935 there were in Ontario well over 9,000 miles of rural lines, approximately 9,000 water heaters and 3,000 electric cookers being installed in the last year. The total capital invested in rural power systems is more than $18 millions, of which some 50 per cent. has been contributed by the Ontario Government. Demonstrations of the uses and advantages of electricity are given frequently, certain demonstration farms being used for this purpose in addition to travelling outfits which visit villages and isolated farms.

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[1] *Rural Electrification and Electro-Farming*, February 1935.

[2] *Journal of the Institution of Electrical Engineers*, vol. 64, p. 801.

As long ago as 1920 there were in Canada electrical installations approaching 10,000 in number on farms which had no public supply of electricity.

In British Columbia electricity is very largely used in the lumber and shingle mills, one of the most important industries in the Province. Dr. H. Vickers[1] has given a very full account of electrical developments in British Columbia, and has stated that the connected load to such mills from the B.C. Electric Railway Co., Ltd. (a large electricity supply company) was (in 1926) 14,314 h.p., in addition to which many of the mills generate their own electric power owing to the existence of an ample supply of fuel in the form of wood waste. There are many advantages of electric-motor drives for the handling of logs and for woodworking machinery in general. Other loads supplied by the same company were 9,986 h.p. to grain elevators, 1,628 h.p. to milling companies, 994 h.p. to bakeries, and 941 h.p. to dairies, creameries, and milk canneries. Loads of 874 h.p. and 715 h.p. were supplied for pumping (drainage, etc.) and for brick manufacturing respectively.

Argentina.—Electricity is transmitted from the cities to the surrounding market-gardening areas for pumping and irrigation purposes. The supply has not yet been extended to the dairying, wheat-growing, and cattle-rearing areas which lie farther away from the cities.

India.—Although a very large percentage of the population of India is engaged in agricultural pursuits, the holdings are for the most part small and the purchasing power of the population is low. In spite of this, there are many promising developments in electrification.

In Madras and the south of India and in Ceylon, electricity is being supplied to tea estates, the supply rates being modified to encourage its use for drying and withering the leaf. Electric motor-driven fans are used in the withering process, and the tea driers are also motor driven, in addition to the use of electricity for lighting purposes.

In the Coimbatore district of Madras, where a large hydroelectric scheme (installed capacity 18,750 kW) has been completed recently, there is already a connected load of about 1,000 h.p. to tea factories and about 260 h.p. for pumping purposes. The developments in this area are remarkable, in view of the great difficulties experienced in constructing transmission lines over mountainous, undeveloped country, which is very unhealthy and has torrential rains for a great part of the year.

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[1] *World Power*, June 1926.

In the whole of India the installed capacity of electrical generating plant in 1932 was some 830,000 kW. In addition to those in Madras, there are other large hydro-electric schemes in the Punjab and the United Provinces, and a number of similar schemes are in the course of construction or are being considered.

Owing to the low rainfall in many districts, irrigation is very necessary, some 50 million acres having been dealt with by various methods. Mr. W. L. Stampe, of the Government Irrigation Branch, United Provinces, has described[1] the Government's irrigation schemes in this district. 28,000 kW (37,500 h.p.) of hydro-electric power will ultimately be available, the retail rate for the energy consumed being about ½*d.* per unit. The irrigation is carried out from tube wells, about 8 kW being supplied to each well. Fifteen hundred such wells will be constructed for the irrigation of about 600,000 acres of cane and wheat. Power is also to be made available for the treatment of the crops, i.e. for crushing sugar-cane, grinding wheat, etc.

About 150 farms already use electricity for pumping, grinding, and crushing, as well as for lighting purposes.

The fact that 11-kV distribution lines can be constructed with local materials at a cost of not more than £110 per mile must be of considerable assistance in rendering possible the low retail rates for energy.

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[1] "Electrical Irrigation in India," *Electrical Review*, November 2nd, 1934.

PART II

ELECTRIFICATION FROM THE POINT OF VIEW OF THE FARMER OR RURAL CONSUMER

CHAPTER V

ELEMENTARY ELECTRICAL ENGINEERING

BEFORE discussing in detail the application of electricity to farming and domestic purposes, it may be well to introduce to the non-technical reader some of the more important facts relating to the practical use of electricity. Only a very brief outline of the subject can be given in the space available, but this may serve to explain the meaning and significance of the various statements, of a somewhat technical nature, which must necessarily be introduced in succeeding chapters.

Work and Energy

Perhaps the most fundamental conceptions in connection with any branch of engineering are those of " work " and " energy."

The everyday use of the term " work," as implying generally " carrying on business," is much too loose for scientific purposes. For such purposes we define " work " as that which is accomplished when a force is moved through a distance, the distance moved being in the same direction as the force.

As an example, if we lift a 56-lb. weight through a *vertical* distance of 1 foot, we do 56 foot-pounds of work. (The foot-pound is the most commonly used unit by which we measure a quantity of work.) Lifting the weight 2 feet *vertically* represents 112 ft.-lb. of work, and so on. The significance of the distance being vertical is that the earth pulls on the weight with a force of 56 lb. *vertically downwards*, so that our force and distance are in the same direction, namely, vertical. If, on the other hand, we move the weight *horizontally* through a distance of 1 foot, we do *no* work, since the movement of the weight *in the direction of the force* is zero.

Energy, in the scientific as well as in the everyday sense, is " capacity for doing work." If a body is capable of doing (say) 1,000 ft.-lb. of work, it is said to possess 1,000 ft.-lb. of energy. (The units in terms of which energy is measured are thus the same as those used in the measurement of work.)

Inanimate objects may possess energy by virtue either of their position (their energy then being referred to as " potential " energy) or of their motion (when their energy is "kinetic"). Simple examples are: (*a*) a stretched spring, which possesses potential energy, since it can exert a force through a distance (and therefore do work) in returning to its unstretched position; (*b*) a moving train, which possesses kinetic energy, since it can overcome a large braking force through a considerable distance before being brought to rest.

There are, in the universe, many recognized forms of energy in addition to what we may term mechanical energy mentioned above. Thus, we may have heat energy, light energy, chemical energy, or electrical energy.

Conservation of Energy

An extremely important principle, known as that of the "conservation of energy," underlies all physical processes. It is that "energy can neither be created nor destroyed," although it may be converted from one form to another. Such conversions are, of course, continually taking place in everyday life as well as in engineering processes. Our food, for example, has chemical energy which our bodies, as "human engines," are capable of converting into heat energy or into mechanical energy (when we exert ourselves to carry out some manual labour). The conversions which are necessary to produce the mechanical energy output of a steam-engine, for example, are interesting. We have, in the first place, heat and light energy, given out by the sun, which was necessary, long ago, to grow the plants which eventually formed the coal burnt in the steam boiler. The coal stores this in the form of chemical energy, which is released and converted first to heat energy, when the coal is burnt to produce steam, and thence to mechanical energy by the steam-engine itself. If, further, the steam-engine is used to drive an electric dynamo, the mechanical energy output is converted to electrical energy, which can be taken from the dynamo and used in electric lamps and electric fires to obtain, once more, light and heat energy as given out by the sun to the coal-forming plants ages ago.

We have in this example a complete cycle of energy conversions, and, according to the principle of the conservation of energy, we actually lose no energy during the various conversions. This does not mean that we are able to produce in the electric lamps and fires exactly the same quantity of energy as was given originally by the sun. There are so-called losses in the various processes due to (say) incomplete burning of the coal, "waste" heat in the boiler which escapes without passing into the steam, mechanical energy " lost " in friction in the steam-engine, and electrical " losses " in the dynamo. It must be realized, however, that these are not actual losses when they are regarded from the point of view of the total energy of the universe. They still exist—although they may not be directly recoverable—in the chemical energy of the coal ash or cinder, in the hot air surrounding the boiler or passing up the chimney of the furnace, or, again, in the form of heat produced by friction and electrical losses. In the most general sense, then, no energy has been lost during the various processes, and it is equally true that no energy has actually been created.

Efficiency.—It is obviously necessary to adopt different units for the measurement of the different forms of energy. We cannot, for example, measure heat energy in terms of the same unit as those used for expressing mechanical energy. Some of these units will be defined later, but all it is necessary to realize here is that each unit has an equivalent in terms of another kind of energy unit : one heat unit is equivalent to so many foot-pounds of mechanical energy and so on, just as, in the measurement of length, 1 foot is equivalent to 12 inches.

If, for any process, we reckon the number of units of energy put into the machine or apparatus and again reckon the number of units of output, we shall *always* find that this latter is equivalent to less energy than that put in. This is because no machine yet invented is so perfect as to function without the so-called losses already mentioned.

The ratio of the output energy to the input energy is called the *efficiency* of the machine or apparatus concerned. Thus, if we get out of a machine energy equivalent to three-quarters of that which is put into it, the machine is said to have an efficiency of 75 per cent.

As already emphasized, the *true* efficiency of the energy conversion during the process within the machine *must* be 100 per cent., but for engineering processes we only measure the useful output of the machine in the form of energy required, those stray amounts of energy which do not appear as direct output being reckoned as losses.

Power.—For engineering purposes, " power " is defined as the " RATE *of doing work or expending energy.*" It is very important to appreciate, at the outset, the very definite distinction between power and energy. A piece of mechanical work such as, for example, pumping 1,000 pounds weight of water from a depth of 40 feet, requires a perfectly definite amount of energy to be expended for its accomplishment, namely, 40,000 ft.-lb. On the other hand, the power required is *not* a fixed quantity, but depends entirely upon whether the pumping is to be done quickly or slowly. Thus, to do this work in 1 minute the pumping equipment would be required to exert a power of 40,000 ft.-lb. per minute, while if the time allowable were 20 minutes, the power necessary would be only 2,000 ft.-lb. per minute.

Power, then, *always* involves a time element, the simplest unit used for its measurement being 1 ft.-lb. per minute. In actual practice this unit is found to be too small for most purposes, and so a unit of 1 horse-power (1 h.p.) is adopted. This unit does not bear a very definite relationship to the power which an actual horse can exert, since this depends upon the type of horse chosen and upon the conditions of working. The definition of 1 h.p. is a power of 33,000 ft.-lb. per minute (or 550 ft.-lb. per second).

It is of interest to note that, under suitable conditions, a good horse can exert, for 8 hours a day, about two-thirds of 1 horse-power as defined above, while a man can exert about one-seventh of 1 horse-power for 10 hours a day. These figures depend, of course, very largely upon the type of work on which the horse or man is engaged.

Energy in Terms of Power and Time

Principally owing to the smallness of the ft.-lb. unit, a method of measuring mechanical work or energy in terms of 1 h.p.-hour has arisen. This unit is the amount of work accomplished when a power of 1 horse-power is exerted for 1 hour. It is easy to see, from the definition of 1 horse-power, that the h.p.-hour is equivalent to 33,000 ft.-lb. multiplied by 60, that is, to 1,980,000 ft.-lb.

This method of measuring energy is of importance, because it is commonly used in electrical engineering. The unit of electrical *power* is 1 kilowatt (or 1,000 watts), which is equivalent to almost exactly $1\frac{1}{3}$ h.p. The most important unit of electrical *energy* is the *kilowatt-hour* (kWh), which may be defined as the energy expended when a power of 1 kilowatt is continued for 1 hour. This unit is often referred to as 1 *Board of Trade* unit, or, more briefly, as 1 *unit.*

It follows, from the above statements, that 1 kWh is equivalent to $1\frac{1}{3}$ h.p.-hours, or 2,640,000 ft.-lb. Alternatively, 1 ft.-lb. is equivalent to $\frac{1}{2,640,000}$ kWh.

Example.—Calculate the energy cost per hour for a pump driven by an electric motor, given :

Rate of delivery of the pump = 250 gallons per hour.
Total lift = 40 feet.
Combined efficiency of the pump and driving motor = 30 per cent.
Cost of electrical energy = 1*d*. per unit.

Now, 1 gallon of water weighs 10 lb., so that the weight to be lifted per hour is 2,500 lb.

$$\text{Work to be done per hour} = 2{,}500 \times 40 \text{ ft.-lb.} = 100{,}000 \text{ ft.-lb.}$$

Hence, the input of electrical energy, disregarding the question of the efficiency of the pumping equipment, must be

$$100{,}000 \times \frac{1}{2{,}640{,}000} = \frac{5}{132} \text{ unit per hour.}$$

Taking the efficiency into account, the consumption of electricity must be :
$\frac{5}{132} \times \frac{100}{30} = \frac{100}{792}$, or approximately $\frac{1}{8}$ unit per hour. The cost of the energy required is thus about $\frac{1}{8}$*d*. per hour.

Further, since the consumption of energy is $\frac{1}{8}$ of a kilowatt-hour per hour, this means that the power input is $\frac{1}{8}$ kilowatt, or $\frac{1}{6}$ h.p.

Heat Equivalent of Electrical Energy

All electrical heating appliances such as cookers, electric fires, etc., are obviously appliances which convert electrical energy directly into heat energy. It is thus important to know the relationship which exists between the units of these two forms of energy in order to determine how many units of electrical energy will be required to produce the amount of heat necessary for any particular purpose.

Perhaps the most convenient heat unit for practical purposes is that known as the British Thermal Unit (B.Th.U.). By definition 1 British Thermal Unit is the heat required to raise the temperature of 1 lb. of water 1 degree Fahrenheit (1° F.). The production of this amount of heat by electrical means requires the use of $\frac{1}{3{,}400}$ part of a unit of electrical energy (i.e. $\frac{1}{3{,}400}$ kilowatt-hour). In other words, 1 unit of electricity will raise the temperature of 3,400 lb. of water 1° F. To boil water from the normal temperature of tap water requires a temperature rise of about 160° F., so that 1 gallon (i.e. 10 lb.) of water would require 1,600 British Thermal units of heat to boil it. This is equivalent to $\frac{1{,}600}{3{,}400}$ of a unit of electrical energy or, roughly, half a unit. We have assumed that all the heat produced by the electricity has gone into the water. Actually we may lose by radiation some 20 or 30 per cent. of the heat produced, so that we shall need to put into the heater (taking 30 per cent. loss) $\frac{100}{70} \times \frac{1{,}600}{3{,}400}$ of a unit of electricity, i.e. about two-thirds of a unit. The cost of boiling the gallon of water in this case is obviously two-thirds of the cost of 1 unit of electricity.

The *time* taken to boil the gallon of water depends upon the rate at which we put energy—whether regarded as electrical energy or heat energy—into it. That is, it depends upon the *power* put into the heater. This power is expressed in watts, and the power consumption, or " wattage," of any heater is almost always stated on the name-plate of the appliance. Thus, suppose that the heater used in the example discussed above is stated to consume 1,500 watts (or $1\frac{1}{2}$ kilowatts), this is another way of saying that the energy consumed by it is $1\frac{1}{2}$ kilowatt-hours (or units) per hour. To boil the gallon of water we require about two-thirds of a unit, so that it will take $\frac{\frac{2}{3}}{1\frac{1}{2}}$ of an hour, i.e. $\frac{4}{9}$ hour, or rather less than 27 minutes.

If we required the water to be boiled more quickly we should use a heater with a greater power consumption. Thus, assuming the radiation losses to be the same in each case, if we used a heater with a consumption of 3,000 watts (3 kilowatts) instead of 1,500 watts, the time taken would be half the above, namely, $13\frac{1}{2}$ minutes, and so on.

The *energy* consumption, and therefore the cost, would be the same in each case, since, although we use double the power in the second case, it is only used for half the time, and the energy is given by multiplying the power by the time for which this power is used.

Summary

Power is expressed in " watts " or " kilowatts " (1 kilowatt being 1,000 watts).

Energy is expressed in " kilowatt-hours " (kWh) or " units " (1 unit being the same as 1 kilowatt-hour).

$$\begin{array}{ccccc} \text{Energy} & = & \text{Power} & \times & \text{Time} \\ \text{in} & & \text{in} & & \text{in} \\ \text{kWh} & & \text{kW} & & \text{hours.} \end{array}$$

The following table illustrates this rule and gives the time, in hours, for which appliances of different power consumptions, in watts, can be used in order that 1 unit, or kilowatt-hour, may be expended in each case. The cost per hour, assuming that electricity costs 1*d.* per unit, is also given for each case. It is not intended to imply that electricity will always cost 1*d.* per unit. The charge for electricity varies, of course, in different districts, but it is easy to work out the costs for any particular price per unit from the corresponding cost at 1*d.* per unit.

TABLE XVI

Power consumption of apparatus (i.e. wattage). Watts.	Time for which apparatus can be run with an expenditure of 1 unit of electricity. Hours.	Cost of running, per hour, at 1*d.* per unit of electricity. *d.*
5	200	$\frac{1}{200}$
10	100	$\frac{1}{100}$
15	$66\frac{2}{3}$	$\frac{3}{200}$
30	$33\frac{1}{3}$	$\frac{3}{100}$
40	25	$\frac{1}{25}$
60	$16\frac{2}{3}$	$\frac{3}{50}$
75	$13\frac{1}{3}$	$\frac{3}{40}$
100	10	$\frac{1}{10}$
250	4	$\frac{1}{4}$
500	2	$\frac{1}{2}$
750	$1\frac{1}{3}$	$\frac{3}{4}$
1,000	1	1
1,500	$\frac{2}{3}$	$1\frac{1}{2}$
2,000	$\frac{1}{2}$	2
3,000	$\frac{1}{3}$	3
4,000	$\frac{1}{4}$	4
5,000	$\frac{1}{5}$	5

The above table applies for all types of electrical apparatus, whether they be for heating, lighting, or power purposes. In the last case, however, the apparatus is usually some form of electric motor, the power consumption of which is not a constant quantity, as it is in the case of lighting and heating apparatus.

Power Consumption of Electric Motors

Electric motors are rated according to their horse-power output rather than in terms of their intake in watts. The " rated horse-power " of a motor is the maximum horse-power which the motor can supply continuously without damage to itself. If a motor is heavily loaded continuously so that it has to supply more than its rated horse-power, it becomes overheated, and may, on this account, suffer considerable damage. The rated horse-power is always stated on the manufacturer's name-plate on the machine. Provided the size of motor for a particular purpose is wisely chosen in the first place, little difficulty arises in practice on account of its rating limit, since most motors are designed so as to be able to supply for short periods a considerably greater horse-power than the normal. Continuous overloading becomes evident to the user through the excessive heating of the motor.

As regards electric power consumption, it is approximately true to say that this is proportional to the power output which the motor is called upon to supply. If the motor were 100 per cent. efficient, this would be exactly true, but since there are losses in all motors, and since some of these losses are constant for all loads, the statement is only an approximation. As an illustration, consider a motor whose rated horse-power is 10, then the electric power consumption, expressed for simplicity in terms of its equivalent horse-power, would probably be somewhat as follows :

	Consumption.
Motor on full load (i.e. 10 h.p. output)	12 h.p.
Motor on half load (i.e. 5 h.p. output)	6¼ h.p.
Motor on quarter load (i.e. 2½ h.p. output)	3¾ h.p.
Motor on no load (i.e. no output)	1 h.p.

Owing to the constant losses already mentioned, the efficiency of a motor, which may, in the case of a fairly large machine of from 10 to 20 h.p., be between 80 per cent. and 90 per cent. at full load, decreases gradually down to about half full load, and then more rapidly, until it is zero when the motor is running unloaded. This is shown in the efficiency curve in Fig. 7. The efficiency (given by $\frac{\text{output}}{\text{input}}$) must obviously be zero when the motor is running unloaded, since, although there is no output, the motor takes a small amount of power from the electric mains in order to overcome the friction and other effects tending to prevent its rotation.

Calculating the efficiencies for the example given above, we have :

$$\text{Full-load efficiency} \quad = \frac{10}{12} \text{ or 83 per cent.}$$

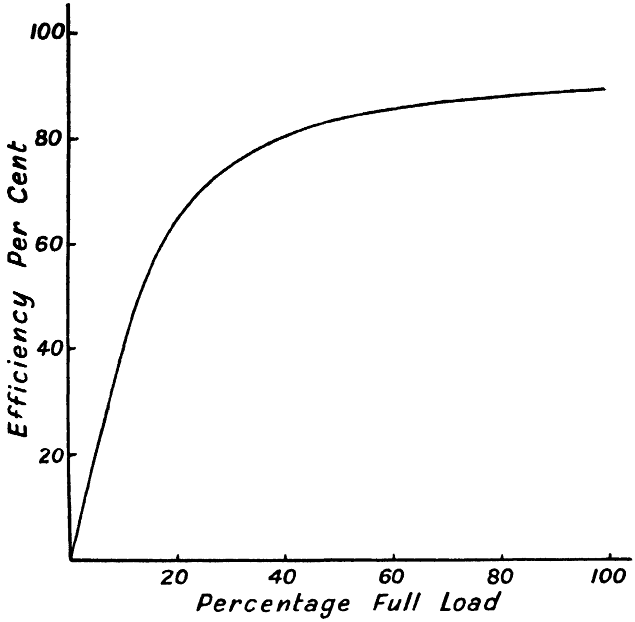

FIG. 7.—EFFICIENCY CURVE FOR AN ELECTRIC MOTOR.

$$\text{Half-load efficiency} = \frac{5}{6\frac{1}{4}} \text{ or 80 per cent.}$$

$$\text{Quarter-load efficiency} = \frac{2\frac{1}{2}}{3\frac{3}{4}} \text{ or 67 per cent.}$$

$$\text{No-load efficiency} = \frac{0}{1} \text{ or 0 per cent.}$$

The energy consumption for one hour in the case of this motor if, during the hour, it is run for ¼ hour on each of the four above-mentioned loads, may be calculated as follows, remembering that 1 kilowatt-hour is equivalent to 1⅓ h.p.-hours :

Energy consumption during ¼ hour on full load

$$= 12 \times \tfrac{1}{4} = 3 \text{ h.p.-hours or } \frac{3}{1\frac{1}{3}} = 2\tfrac{1}{4} \text{ kilowatt-hours.}$$

Energy consumption during ¼ hour on half load

$$= 6\tfrac{1}{4} \times \tfrac{1}{4} = 1\tfrac{9}{16} \text{ h.p.-hours or } \frac{1\frac{9}{16}}{1\frac{1}{3}} = 1\tfrac{11}{64} \text{ kilowatt-hours.}$$

Energy consumption during $\frac{1}{4}$ hour on quarter load

$$= 3\tfrac{3}{4} \times \tfrac{1}{4} = \tfrac{15}{16} \text{ h.p.-hours or } \frac{\frac{15}{16}}{1\frac{1}{3}} = \tfrac{45}{64} \text{ kilowatt-hour.}$$

Energy consumption during $\frac{1}{4}$ hour on no load

$$= 1 \times \tfrac{1}{4} = \tfrac{1}{4} \text{ h.p.-hour or } \frac{\frac{1}{4}}{1\frac{1}{3}} = \tfrac{3}{16} \text{ kilowatt-hour.}$$

The total energy consumption in the hour is thus the sum of $2\frac{1}{4}$, $1\frac{11}{64}$, $\frac{45}{64}$, and $\frac{3}{16}$ kilowatt-hours, which is $4\frac{5}{16}$ kilowatt-hours (or units of electrical energy). At 1*d.* per unit, the cost per hour under these conditions would thus be $4\frac{5}{16}$ pence or $4\frac{1}{4}$*d.* approximately.

In practice it is often very difficult to maintain the power output of a motor constant during ordinary farm processes. Again, there is no method of determining, without recourse to measuring apparatus with which no ordinary farm would be equipped, the actual load on the motor during such processes.

Perhaps the best rule one can give in connection with power consumption of motors is that such consumption may be taken as 1,000 watts per rated horse-power, assuming the motor to be run on full load all the time. Thus a 5-h.p. motor on full load would take about 5,000 watts, and from Table XVI the cost per hour of running the motor on full load would be 5*d.*, assuming electricity to cost 1*d.* per unit.

The difficulty of making a more precise estimate of cost is apparent if one considers a case such as that of a motor driving a chaff- or root-cutter. In general, the power consumption will obviously depend greatly upon the rate of feeding the machine with the material to be cut. If the machine is fed continuously, so that it is cutting all the time, the average load on the motor may be maintained at round about its full load value, but even so, there may be a considerable variation of the load during each individual cut and also between any two of these, owing to the varying compactness of the material being cut.

Choice of Motor Size

Since the efficiency of a motor or, otherwise stated, its output per unit of electricity input, is greatest when the motor is loaded with its full rated horse-power, it is uneconomical to run motors on light loads. The performance of motors is, of course, quite satisfactory on such loads, but the cost per h.p.-hour of output is greater than when they are more heavily loaded. Thus, if a farm machine, when working under normal conditions, requires 2 h.p. to drive it, then a 2-h.p. electric motor should be used for the purpose, it being uneconomical, both from the point of view of running and of initial capital cost, to install a motor of greater horse-power. There is sometimes a feeling that a more powerful motor would, in some undefinable way, do the job better than a smaller one, but this feeling is quite unjustifiable.

The question of the speed of a motor does not influence this question of size. There is usually a certain speed which is best suited to the working of a particular machine, and the motor driving it should be one whose normal speed is as near as possible to this. The speed of a motor and its rated horse-power are not connected in any intimate way, so that it is possible to obtain motors of the same rated horse-power having widely different normal running speeds. There is, of course, some reduction of speed as the load on a motor is increased, but with the types of motor used in farm work this reduction is very small, and may be neglected when it is remembered that the exact speed of driving a farm machine is not usually a critical matter.

The above remarks regarding the most suitable size of motor must be taken as applying more particularly to the case of a stationary motor driving a single machine. If the size of farm or the amount of work to be done does not justify the capital expenditure on a number of separate motors, a portable motor may be used. In this case there is no alternative to choosing a motor of such a size as will deal satisfactorily with the biggest job to be undertaken and allowing it to run on light load when used for the smaller jobs. The motor will then be running at about its full load—and maximum efficiency—when used for the larger power purposes, it being less important to run at maximum efficiency in the case of the smaller jobs.

Load Factor

We have seen that there is a very definite limit to the power which any particular motor is capable of producing continuously. In general, the greater the power required of the motor, the larger and more costly will it be.

These facts apply in exactly the same way in the case of the machines used to generate the electricity in electric power stations, and have, therefore, a direct bearing upon generating costs. A little consideration will show that the consumer, by the way in which he uses his electrical apparatus, also influences these costs. Thus, suppose a consumer uses all his electrical appliances —cookers, fires, motors, etc.—at the same time of the day. The supply undertaking catering for his demand must have plant of a corresponding output on account of this consumer, and since it is unlikely that the power demand will exist for more than a short period, the result is that a much larger generating plant must be installed in the power station than that which would be sufficient to deal with the *average* demand of the consumer reckoned over twenty-four hours. Although one consumer alone may not have much influence upon the capacity of the generating plant required, it is clear that similar behaviour on the part of a number of consumers would increase considerably the size of generating plant, with a consequent increase in the capital cost and interest and depreciation charges on such plant. On the other hand, the supply company receives no compensating revenue, since, although the power demand is heavy, it only exists for a short time, so that the energy consumed (i.e. power multiplied by time) is not large. If the method of charging for the supply is by means of a flat rate of so much per unit of energy consumed, it is obvious that the supply company is the loser on account of such short-period heavy demands of power.

The amount of energy actually used by a consumer divided by the amount which would have been consumed had he taken his maximum power continuously is called the " load factor " of the consumer's load. This is almost always less than 1, and in the case discussed above, might be a very small fraction. Because of the disadvantage to the supply company of a low load factor, a method of charging is sometimes used which penalizes the consumer who uses large amounts of power for only short periods. This is known as the " maximum demand " method of charging, and consists of a quarterly or annual charge per kilowatt of the maximum power demand, together with a small charge per unit of energy consumed. This ensures that the supply company receives adequate revenue to cover that part of the total cost of supply which depends upon the power demand and also that part which depends upon the working costs (i.e. fuel costs, etc.).

It is seldom possible, of course, for a consumer to arrange that his power demand shall be uniform, but sometimes a little thought might prevent the use of several large power loads existing at the same time. If the maximum-demand method of charging is adopted, it is very definitely to the user's advantage to take such thought, and in any event it tends to reduce the costs of supply to the general good.

Fortunately for the supply company, the individual maximum power demands of consumers do not all occur at the same time of the day. The maximum demand upon the generating station is thus always less than the sum of the individual maximum demands. This characteristic is dealt with technically under the title "diversity factor," which is defined as the sum of the individual maximum demands divided by the actual maximum demand upon the generating station. This is almost always greater than 1, just as the load factor is almost always less than 1.

Measurement of Power and Energy

In electrical engineering practice, power is measured by means of a "wattmeter" and energy by a "watt-hour meter." On most electrified farms only the latter instrument will be available, this being installed by the electricity supply undertaking in order to measure the total energy supplied over a period of time and thus to enable the account to be rendered to the consumer. The readings of these meters are usually taken by the company's representatives quarterly, and in many instances little notice is taken of them by the consumer. It is, however, a simple matter to read the indications of such instruments and much interesting information regarding the energy consumption during particular pieces of work—and hence the cost of doing the work—can be obtained from them.

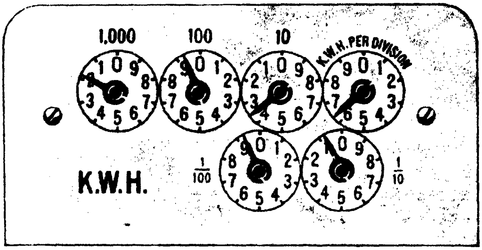

Fig. 8.—Dials of a Watt-hour Meter.
By courtesy of Metropolitan-Vickers Electrical Co., Ltd.

For this reason an illustration of the registering mechanism of a typical watt-hour meter is given in Fig. 8. The various dials—usually six in number—indicate the 1,000's, 100's, 10's units, tenths, and hundredths of units which have been used to date. For example, from the dials in Fig. 8 the energy used up to the time of reading is $1{,}936\frac{9}{100}$ units. Suppose that, immediately after the reading has been taken, an electric motor is used for two hours (no other electrical apparatus being in use at the same time) and that at the end of this period the meter reads $1{,}945\frac{29}{100}$ units, this means that the motor has used, in two hours, $9\frac{2}{10}$ units (i.e. $9\frac{2}{10}$ kilowatt-hours). At 1*d*. per unit, the cost will have been $9\frac{2}{10}d.$, while the average power used is given by dividing the energy consumption by the time in hours, i.e. $\frac{9\frac{2}{10}}{2}$, which is $4\frac{6}{10}$ kilowatts. This is roughly equivalent to an average power of 4½ h.p. output. In this way a guide as to the cost of any particular piece of work may be obtained from the meter readings.

The above example takes no account of any fixed charge in the cost of electrical energy. There is often such a fixed charge per quarter in addition to the unit charge—taken above as 1*d.* per unit. This charge will have the effect of increasing the cost of the work by an amount which will be reduced in proportion to the total number of units used per quarter.

It is very instructive for a consumer to check his energy consumption and cost as suggested above rather than to accept published statements, which must obviously be very general in character and will probably apply only very roughly to his particular case, owing to the large variation in the farm machines to be driven and in the individual methods of using these machines.

CHAPTER VI

ELEMENTARY ELECTRICAL ENGINEERING
(*continued*)

HAVING discussed, in the preceding chapter, the questions of energy and power, it is now necessary to enter into rather more detail regarding the actual layout of electric circuits and the pieces of apparatus most commonly used in connection with them. These are, perhaps, primarily the concern of the installation engineer, but it is desirable that the user should have some conception of the functions of the various parts of the installation in order that he may use them with some discrimination and to his better advantage.

The Electric Circuit

Electricity can be made to flow, under pressure, through a complete path, or circuit, just as water may be forced through a system of pipes by means of a pump which exerts the necessary pressure to overcome the resistance to motion due to frictional effects within the pipes. Such a comparison with the flow of water is perhaps the best method of obtaining a clear mental picture of the flow of electricity in an electric circuit and of the various phenomena resulting from this flow. Although not a perfect analogy, there are so many points of similarity between the two cases that the comparison will be made in the following discussion in order to explain the various effects and technical terms to be dealt with.

Fig. 9 compares a water circuit with an electric circuit. In diagram (*a*) we have a pump exerting (say) 100 units of pressure and causing a flow of water through the circuit and the apparatus which is to be supplied with water. The pressure at the apparatus is (say) only 90 units, because 10 units are lost, or absorbed, in overcoming the frictional resistance of the pipes acting against the water flow. Two valves are shown, these being opened to allow the water to flow or closed to stop the flow.

The corresponding electric circuit is shown in diagram (*b*). An electrical generator serves a similar purpose to that of the pump in that it forces an electric current at (say) 100 units of electrical

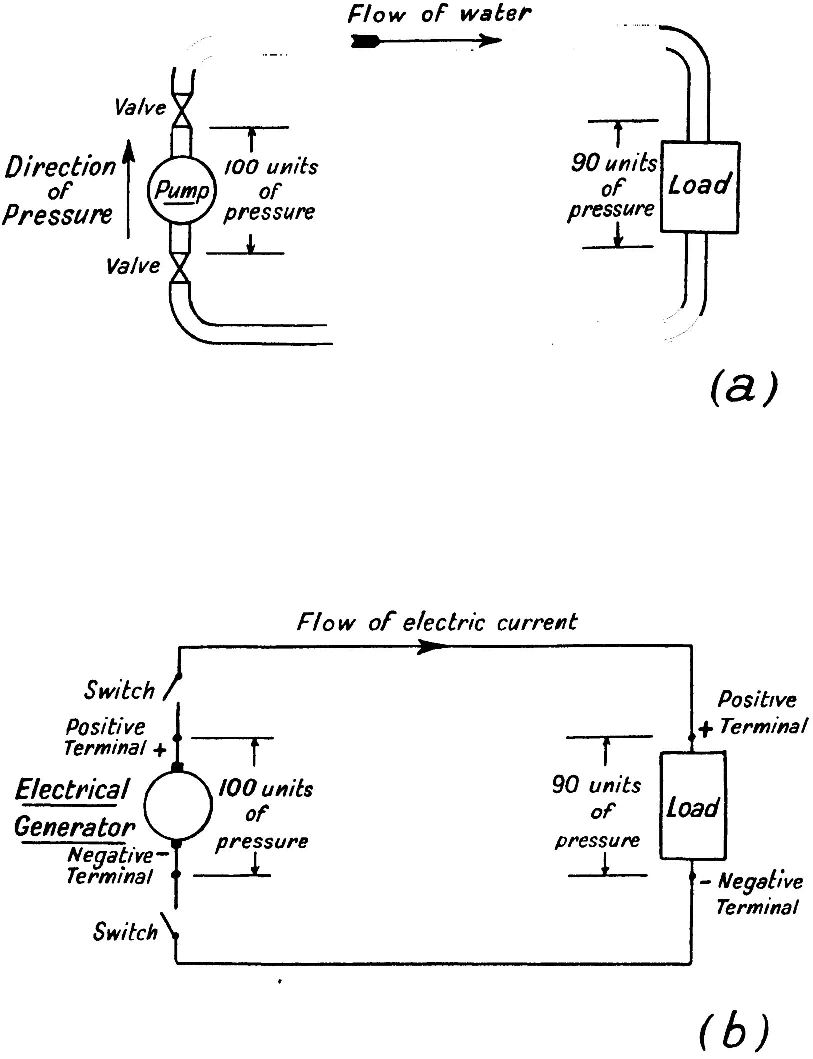

FIG. 9.—COMPARISON OF HYDRAULIC AND ELECTRIC CIRCUITS.

pressure (the name given the unit of electrical pressure is the "volt") to flow through the circuit and the apparatus to be supplied with electricity. The pressure at the apparatus is (say) only 90 volts, owing to the fact that 10 volts are absorbed in forcing the electricity through the circuit external to the generator and apparatus. The circuit has " electrical resistance," the effect of which is similar to that of the frictional resistance in the water circuit. In the electric circuit the connections between the various component parts are made by wires instead of by pipes as in the water circuit. These wires are usually of copper, for the reason that the electrical resistance of wires of this metal is less than that of almost any other metal wires of the same size.

As regards the direction of flow of the electricity, the name " positive terminal " is given to that end of the generator out of which the electricity flows, the end to which the electricity returns being called the " negative terminal." These are often indicated simply by the symbols + and − respectively.

In the case of the apparatus supplied with electricity the positive terminal (+) is the end *into* which electricity flows and the negative terminal (−) that by which the electricity flows *out.*

An electric current always flows from positive to negative, just as water always flows from a higher level to a lower level.

Referring again to Fig. 9, it will be noticed that, in Diagram (*b*), there are two " switches," one on each side of the generator, which correspond to the valves of diagram (*a*). To complete the circuit, and so allow current to flow, we " *close* " the switches (this corresponding to *opening* the valves) and to interrupt the current we " *open* " the switches (this corresponding to *closing* the valves). These switches are often built into a single box or case and arranged so that they can be closed or opened simultaneously by raising or lowering the switch handle. The whole device is then referred to as a " double-pole switch." In some cases, only one switch is used instead of the two shown, and is then referred to as a " single-pole switch."

Time Switches

A time switch is a device which opens and closes an electric circuit automatically at certain fixed and predetermined times. The use of such a switch is very convenient, since it requires winding—if clockwork driven—only once a fortnight or thereabouts, and in the meantime carries out the switching operations required of it without any attention from the user. They are commonly used on electric street-lighting systems, and on the farm, also, their principal application has been the operation of intermittent lighting circuits, such as those for lighting poultry houses and for intensive illumination in greenhouses. They can be adjusted very simply to carry out either two or four switching

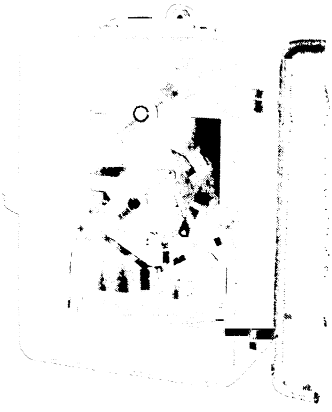

FIG. 10.—SHOWING THE CONSTRUCTION OF A TIME SWITCH.

By courtesy of the General Electric Co., Ltd.

operations a day at fixed times, such as, for example, " on " at 6 a.m., " off " at 7.30 a.m., " on " at 4.30 p.m., " off " at 7 p.m. The mechanism is simple and reliable, and the operations are carried out within a minute or so of the times to which the switch is set. They may be driven by clockwork, which requires periodic winding, or they may be self-winding. The construction of a common form of time switch is shown in Fig. 10.

Direct and Alternating Currents

There are two kinds of electric current, namely, Direct Current (D.C.) and Alternating Current (A.C.). These are produced, of course, by different types of electrical generators in the power stations. If a district is to be supplied with direct-current electricity, the electrical pressure supplied to the mains will be unidirectional, as in diagram (*b*) of Fig. 9, and a D.C. generator will be used in the power station for the purpose. If, on the other hand, the supply is to be alternating current, an alternating-current generator—often called an " alternator "—is used at the generating station. In this case, the pressure produced by the alternator is not unidirectional, but rapidly alternates, the terminals being alternately positive, negative, positive, negative, and so on. In practice the reversal of the direction of the pressure usually takes place every hundredth of a second, and the current produced in the electric circuit, including the consumer's apparatus, reverses direction at the same rate.

In spite of the difference in character between the two types of current, the statements made both above and in the preceding chapter apply in the same way to both types, and, indeed, so far as the consumer is concerned, there is little difference between the two kinds of supply when considering the general use of electricity. Many pieces of electrical apparatus, such as lamps, electric fires, and heaters, may be operated on either D.C. or A.C., but there are a few appliances, such as electric motors and wireless sets, whose construction depends upon the type of supply upon which they are to be used. When purchasing such apparatus the consumer must, therefore, take into account the type of supply in his district.

One very important difference between D.C. and A.C. supplies which has caused the latter to be very largely adopted in recent years in preference to the former [1] is that the pressure of an A.C. supply can be increased or decreased, by means of an appliance called a " transformer," very easily and with very little loss of power in the process, whereas it is much more difficult, and more expensive, to change the pressure of a D.C. supply. Now, it is very desirable that electric power should be transmitted from the power station to the district to be supplied at a high pressure, since the higher the pressure the less the percentage loss of power in the transmission.

With A.C. it is convenient, and is the general practice, to generate at a comparatively low pressure in the generating station, to use a transformer to increase this pressure to a very high value for transmission purposes, and then to use another transformer to reduce the pressure to a usable value at the far end before giving the supply to the consumer.

It should be noted that the consumer himself could, by using another transformer, still further reduce the pressure if he so desired. In certain cases this may be desirable.

Electrical Pressure or Voltage

The unit in terms of which electrical pressure is measured is the " volt," and for this reason we often speak of the " voltage " of a supply instead of the " pressure," of which it is a measure.

Returning again to the water analogy, domestic water supplies are given at a water pressure which is low enough to be easily controlled by ordinary water taps and which is not likely to cause bursting of water pipes of ordinary and convenient strength. Again, the water pressure supplied, except when conditions are abnormal, varies little from day to day.

In the same way, the electrical pressure or voltage supplied to a consumer is conveniently low and constant in value, so that it does not cause damage to the consumer's apparatus or involve danger to the consumer himself. This statement requires, perhaps, some explanation. Considering the apparatus first, it must be realized that almost all electrical appliances are designed and manufactured for a particular voltage. Thus, one electric fire (A) may be designed to be used on a supply of from 230 to 250 volts (a little flexibility is usually allowable as regards the exact voltage of use), whereas another (B) may be designed for a voltage of 200 to 220.

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[1] Only about 20 per cent. of the total number of units now sold by authorized undertakings in Great Britain are in the form of direct current.

If fire A is used on a 200-volt supply no damage will be done, but it will give less than the proper amount of heat. On the other hand, if fire B is used on a 250-volt supply, it will be overheated, and may be quickly " burnt out," requiring a replacement of the heating element.

Electric Shock

As regards danger to the consumer, there is always the possibility of an electric shock from the supply, although this is remote if the electrical installation is properly constructed and suitable care is taken in its use. It is difficult to give precise figures regarding what should be considered as a dangerous voltage, because the result of a person's coming into contact with a given voltage depends upon the physical characteristics and condition of that person and upon the way in which the contact is made. For example, if the contact is made by a person with moist hands firmly grasping a " live " wire while, at the same time, standing upon wet ground, the shock received from a given voltage would be much more severe than that received from a light contact with the live wire whilst the person is standing upon a dry floor.

Speaking generally, however, voltages above 400 to 500 volts must be regarded as dangerous, and for this reason the pressures most commonly used for domestic and farm purposes are of the order of from 200 to 250 volts.

Lest the reader should exaggerate the dangers of using electrical apparatus, it should be pointed out that Government Reports on electrical accidents show that the number of fatal accidents in factories and workshops in this country due to electricity in a ten-year period total only about 250, or 25 per year. This is, of course, an exceedingly small percentage of the number of persons who use electricity during a year. The data given in these reports indicate : (*a*) that the number of such accidents does not appear to be increasing with the largely increasing use of electricity ; (*b*) that the number of fatalities amongst unskilled workers is about the same as amongst skilled electrical workers ; (*c*) that the number of fatalities at different voltages shows that these are distributed fairly uniformly over the range of voltage above 200 volts. There is, perhaps, a tendency for more fatal accidents to occur with A.C. than with D.C. and with the lower voltages rather than with high, but this is explainable by the facts that A.C. is now much commoner than D.C. and also that most of the supplies likely to come in contact with users are of low voltage, the high-voltage systems being far more isolated from consumers.

Insulation

In the same way that hot-water or steam pipes are wrapped with some material which is a non-conductor of heat, in order to prevent the heat from escaping, and also to avoid the risk of burning anyone who might accidentally touch the pipes, so electric wiring is wrapped with some electrically non-conducting material referred to as " insulation." Just as metals are usually good conductors of heat, so they are good conductors of electricity, while materials such as rubber, paper, oil, glass, cotton (if dry), wood, etc., are non-conductors or insulating materials. The electric wiring and the working parts of electrical appliances are insulated so that electricity is prevented from leaking out of the system, and also it is made difficult for the user to come into electrical contact with the live parts of the circuit.

The " live " parts of motors and the heating elements of electric fires and cookers are insulated from the outer case or frame of the motor or fire so that the user may touch these cases quite safely. In many instances the outer parts of electrical apparatus are placed in electrical connection with earth by joining them to water pipes, or to special " earth plates," which are themselves embedded in, and in electrical contact with, the earth. Should a " fault " occur on the system, so that the live parts become connected to the exposed metal parts of the apparatus, the electricity is conducted directly to earth, and a device is inserted in the electric circuit which, under these circumstances, causes the supply to be switched off, so preventing the danger of shock to the user.

It is essential that the insulation of any system of electric wiring shall be as nearly as possible perfect throughout its length, otherwise a leakage will occur at the faulty point. Various factors may produce faulty insulation, common causes of trouble being: (*a*) overheating of the wire or cable within the insulation, which impoverishes the insulating material by making it brittle, so that it is easily cracked ; (*b*) abrasion of the insulation, due to being constantly rubbed against some rough surface ; (*c*) moisture or acid fumes, which bring about either a physical or chemical change in the insulating material, rendering it partially conducting.

Overheating of the wires may be caused by continuously passing through them a higher current than that which they are intended to carry. The " current-carrying capacity " of cables depends upon their size (cross-sectional area) and upon the way in which they are insulated. (The pressure drop in various parts of the electric circuit, owing to its electrical resistance, has already been mentioned. There is a loss of power associated with this drop of pressure, and this power loss takes the form of heat, so that excessive current produces excessive heating.) Obviously, the greater the thickness of insulation, the less easy is it to conduct away the heat produced. Electric current is measured in " amperes " and a rough rule for current-carrying capacity of wires is that they will carry, without overheating, about 1,000 amperes of current per square inch of cross-sectional area. Thus, a wire whose cross-section is $\frac{1}{100}$ square inch will carry about 10 amperes.

Moisture quickly renders insulation imperfect, and to keep the cables dry and also to protect them from mechanical damage, they are often enclosed within steel tubes or are themselves supplied with a lead covering or sheath. In the case of cables running in stables, cow-sheds, and other farm buildings in which there may be acid fumes, neither steel tubes nor lead sheathing are satisfactory owing to the chemical action of the fumes on the metal. In such situations cables having a covering of tough rubber are best, such cables being manufactured by several firms for the purpose.

Before leaving the subject of insulation, it should be pointed out that, since air is a non-conductor, or insulator, it is not always necessary to provide insulation such as a rubber covering throughout the entire length of the circuit, provided adequate insulation is used at the points of suspension, and provided, also, that the wires are so situated that they are not likely to be brought into direct contact with one another or with anything in direct electrical contact with earth. For this reason the wires of overhead transmission lines, such as those of the National Grid System, are bare copper or aluminium wires, but ample insulation is provided at all points of suspension by means of the strings of porcelain insulators, to the lower ends of which the wires are attached. The porcelain, which is an insulating material, prevents leakage of electricity from the wires down the steel towers to earth, while between the towers the air acts as the insulating material. This method of insulation may be used, however, only when there is no danger of the bare wires being touched by animals or human beings and when there is no reasonable chance of conducting material falling across the wires and so producing a short-circuit. (The meaning of the term "short-circuit" will be appreciated after reading the following paragraphs.)

Electric Current and Resistance

We measure flow of water in gallons per second or cubic feet per second, and, similarly, we measure flow of electricity in "coulombs" per second, a coulomb being a unit of quantity of electricity just as a cubic foot is a unit of quantity of water. Again, in speaking of the flow of water, the unit "1 cusec" is used to express a flow of 1 cubic foot per second. In electricity we use the unit "1 ampere" to express a flow of 1 coulomb per second, and since we are chiefly interested, in electrical practice, with current rather than quantity, the ampere is much more commonly used than the coulomb. In fact, if we wish to speak of a quantity of electricity, we very commonly express it in "ampere-hours," 1 ampere-hour being the quantity of electricity supplied when a current of 1 ampere flows for 1 hour.

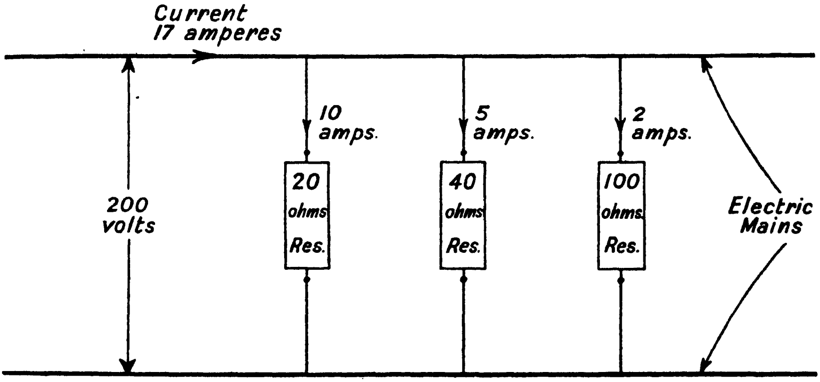

FIG. 11.

By comparison, we might express 1,000,000 cubic feet of water as that supplied when a current of 10,000 cubic feet per hour flows for 100 hours.

Although, as pointed out in an earlier paragraph, the pressure, or voltage, of an electric supply system is a constant quantity, such as 200 volts, the current flowing in any particular circuit supplied by this system is not constant, but depends upon the electrical resistance of the circuit. Fig. 11 illustrates this point. In this figure no attempt is made to show the actual layout or construction of the apparatus; switches, fuses, etc., being omitted.

It shows three pieces of electrical apparatus (such as, for example, an electric fire, a water heater, and an electric iron) connected to the electric mains. Note that the two ends, or terminals, of each piece of apparatus are connected to different wires of the mains, so that the full electric pressure (200 volts in this case) is applied to each piece of apparatus, this being the usual method of connection. Drop of pressure between the points of connection of the various devices is assumed to be so small as to be negligible.

Now, in this example, the three pieces of apparatus differ in construction and offer to the passage of current different electrical resistances, expressed by 20 ohms, 40 ohms, and 100 ohms (1 ohm being the unit in terms of which electrical resistance is measured). From one of the most fundamental laws of electricity—Ohm's law—the current, in amperes, flowing in any piece of apparatus is found by dividing the pressure, or voltage, applied to it by the electrical resistance of the apparatus itself. The currents taken from the mains in this case are thus respectively 10 amperes (i.e. 200 divided by 20), 5 amperes, and 2 amperes, or 17 amperes altogether. In practice the resistance of a piece of apparatus is seldom stated on its name-plate, it being more usual to state the current (in amperes) or the power (in watts) taken when the apparatus is connected to a supply of the voltage for which it was designed.

Method of Connecting Apparatus to the Supply

It should be noted that the method of connecting electrical appliances to the supply is normally that indicated in Fig. 11, this being called the " parallel " method of connection. In this case the full pressure, or voltage, is applied to each piece of apparatus. Fig. 12 illustrates an alternative method, called the " series " connection, in which the various appliances or parts of the circuit are connected end-to-end, so that the same current passes through all of them. In this case the current flowing is found by dividing the mains voltage by the *sum* of the individual resistances ; thus, in Fig. 12 the two appliances in series have resistances of 10 ohms and 30 ohms respectively, giving a total resistance of 40 ohms. The current flowing through them both is thus 5 amperes (i.e. 200 divided by 40). In such a case the full pressure of the mains (200 volts) is not applied to each appliance. Actually the pressures across the two would be 50 volts and 150 volts respectively, the pressure dividing in proportion to the resistances. Owing to the fact that each individual piece of apparatus, when connected in series with others, receives less than the full voltage for which it was designed, such appliances as electric lamps, electric fires, etc., are not connected in series. For example, if two similar lamps, each intended for use on a 200-volt supply, were connected in series across such a supply, each would receive only half the full pressure, namely, 100 volts, and in consequence would give far less than its normal amount of light. It is necessary, of course, to connect certain apparatus, such as switches and fuses, in series with various electrical appliances, but these are always of such low resistance that they do not reduce appreciably the pressure applied to the appliance itself.

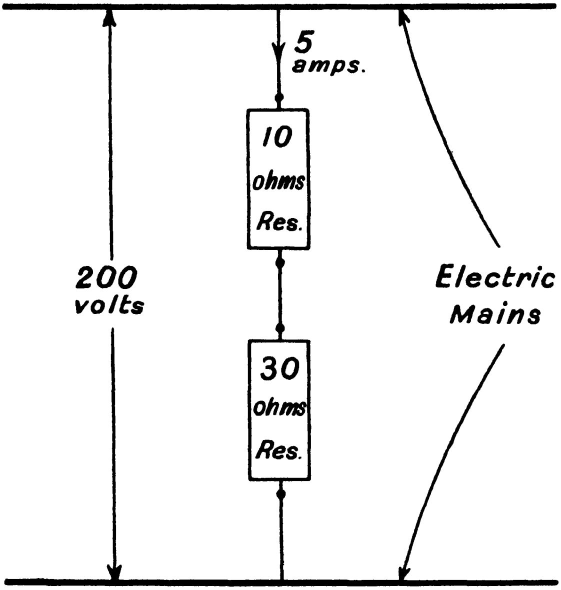

FIG. 12.

Short-circuits—Fuses and Circuit Breakers

From the two preceding paragraphs it will be realized that the smaller the electrical resistance of an electrical appliance the greater the current which will pass through it when a given voltage is applied to it. It follows, therefore, that if, by chance, the two electric mains become connected together, either directly or through something having only a very small electrical resistance, a very large current will flow through this connection, and, consequently, through the mains themselves. Such an unintentional low-resistance connection between the two mains is referred to as a " short-circuit," and must be guarded against owing to the damage caused to the mains by the heat produced by the very heavy current if this is allowed to continue for any appreciable time.

If the electric mains consisted of two bare wires, any metal, or electrically conducting object falling across them, would produce a short-circuit, and in the case of insulated cables care must be taken that the insulation is not cut or removed in any way so as to expose the wires themselves. As already mentioned, moisture or acid fumes cause deterioration of insulation, and these may be responsible for a short-circuit, unless suitable cables are used to resist them. The importance of satisfactorily insulated cables and of their careful treatment when installed in the buildings cannot be over-emphasized, as in addition to the possible damage to the cables themselves, a short-circuit is always attended by the risk of shock and of fire.

Fuses are installed to break the circuit and so cut off the electricity supply if a short-circuit occurs, or in the event of more current being taken from the mains than the cables installed can carry without damage. A fuse consists of a small length of copper, tin, or lead wire or other conducting material enclosed within (usually) a porcelain box or case. The fuse is connected in series with a piece of apparatus, and is so small in cross-section that it becomes overheated and melts—thus breaking the circuit—if the apparatus in series with it takes more than its normal current. It thus acts like the weakest link in a chain, which breaks when any excessive stress is applied. By enclosing the fuse within a porcelain container, we ensure that the heat produced by its melting does no damage to adjacent, possibly inflammable, material. Asbestos tubes and pads are often used to enclose the wire itself and to prevent the formation of an arc within the fuse box. Otherwise unexplained fires are so often—though seldom justifiably—attributed to an electrical short-circuit that the risk of fire has become greatly exaggerated. Since a fuse is not sufficiently quick-acting to prevent the possibility of the silk or cotton braiding of flexible cables becoming ignited by a short-circuit, especially on direct-current systems, it is certainly advisable to use rubber-sheathed cable rather than braided cable in situations where the fire risk might be serious. With normal precautions, however, it is safe to say that the chances of a fire being caused by the electric wiring are very small.

When a fuse is " blown " it is advisable to examine the circuit and apparatus in order to discover the cause of the trouble before attempting to replace the fuse. In the case of circuits intended for only small currents, such as lighting circuits, the replacement of the fuse is a simple matter. The main switch is first opened to cut off the electricity supply and a new piece of fuse wire, of suitable size and material, is fixed in position in the fuse holder, which can be removed for the purpose. The construction of a common form of fuse holder is shown in Fig. 13.

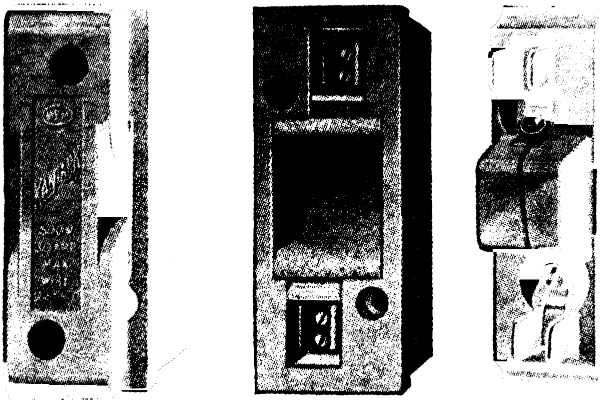

FIG. 13.—FUSE HOLDER WITH FUSE IN PLACE (ON LEFT) AND REMOVED (ON RIGHT).

By courtesy of Midland Electric Manufacturing Co.

In circuits which normally carry heavy currents, cartridge-type fuses are often used. In these the wire is enclosed in a tube, or cartridge, containing some non-inflammable powder such as chalk. A new cartridge must be inserted in such cases.

" Circuit breakers " are used instead of fuses for the protection of circuits which carry very heavy currents. These are pieces of apparatus which automatically open the circuit, through an electrically operated mechanism, when an excessive current flows. There is no question of replacement as with a fuse. When the circuit breaker " trips " as a result of excessive current, the moving portion merely moves from the " on " to the " off " position. The handle of the device is merely pushed into the " on " position after rectifying the fault which caused the breaker to open. Although circuit breakers are not very common on farms, they may be used for the protection of electric motors. When so used, the mechanism of the breaker can be adjusted so that it trips and thus stops the motor if the latter is overloaded. There is thus protection of the motor itself of a more delicate nature than that which can be provided by fuses. Since the current taken when a motor is starting up is usually greater than that when the machine is running normally, a device is included in these breakers to give a time-lag, which ensures that the breaker does not operate under temporary heavy currents, but only when these are continued long enough to necessitate stoppage for the protection of the motor from damage.

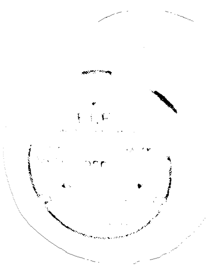

FIG. 14.—CIRCUIT BREAKER FOR SMALL MOTOR.

By courtesy of General Electric Co., Ltd.

A circuit breaker for use with small motors is illustrated in Fig. 14.

Electric Power

We have mentioned electric power on many occasions already, but, until now, we have not been in a position to discuss the relationship between power and its component parts, voltage and current.

Now, it should not be difficult, in considering once more the analogy of water power, to appreciate that the power which might be generated by means of a water-wheel depends principally upon two factors, namely, the flow of water (measured in gallons per second or cubic feet per second) and upon the "head" or pressure behind the water. Thus it is possible that the power obtainable from a small mountain stream, with plenty of pressure, owing to the height from which it descends, but with very little flow of water, may be the same as that obtainable from a river in which there is a considerable flow of water (due to the size of the river), but very little pressure behind it, since it is flowing along ground which is almost level.

In the same way electric power depends upon both the pressure (or voltage) and the current (in amperes). A certain amount of electric power may be the result of a small current flowing at a high voltage (comparable with the mountain stream in the water-power analogy), or it may be the result of a large current flowing at a low voltage (comparable with the river).

As already stated, electric power is measured in "watts," or, if the power is large, in " kilowatts," 1 kilowatt being 1,000 watts. We obtain the power or " wattage " by multiplying the current (in amperes) by the pressure (in volts). Thus, if an appliance takes a current of 5 amperes, the pressure of the mains being 220 volts, the power is 5 multiplied by 220, or 1,100 watts, otherwise $1\frac{1}{10}$ kilowatts. Alternatively, the current taken by a 100-watt lamp when supplied from 200-volt mains is $\frac{1}{2}$ ampere.

It should now be clear that pieces of apparatus such as motors and electric cookers, which absorb comparatively large amounts of power, take much more current than such appliances as lamps, whose wattage is small. For this reason the cables feeding the former, and the switches and other fittings for them, must be heavier, on account of the larger current to be carried, than those used for lighting circuits.

In high-voltage systems, such as the National Grid, whose voltage is 132,000, a large amount of power can be transmitted as the result of a comparatively small current, so that the size of the cables used need not be very large. Partially counterbalancing this advantage there is, of course, the necessity for much greater insulation on account of the very high voltage.

Electric Motors and Motor Starters

The power consumption of electric motors was discussed in the previous chapter, where some information regarding their efficiency and on the choice of suitable sizes was also given. A detailed account of the construction and action of various types of motors would be out of place in this book. It must suffice that all electric motors, whether for direct or alternating current, operate owing to a magnetic attraction between the fixed and rotating parts, which is fundamentally the same action as the well-known attraction of a simple magnet for a piece of iron placed near to it.

The construction of most motors for use on farms is very robust and the depreciation with time is very small. As regards the purely electrical portions of motors, the only concern of the user need be that of ensuring that the insulation of the working parts is not damaged by dampness, dirt, or overheating. If the motor is of the enclosed type, there is little need for attention as regards the first two of these. From the mechanical point of view the requirements of motors as regards oiling of bearings, etc., are much the same as those of any other form of rotating machine, but it can be seen that the maintenance factor on this account is not a very serious item.

Except in the case of very small sizes, all motors must be started by means of a suitable " starter," which is a device serving a somewhat similar purpose to that of a clutch on a motor-car. The clutch is used to allow the motor-car engine to take up the drive gradually and the electric motor starter applies gradually to the motor the voltage of the mains. If the motor were connected directly to the supply mains whilst stationary it would take an exceedingly heavy current, which would immediately blow the fuses and would probably damage the motor seriously. The starter limits the current until the motor has attained its full speed and can safely be connected directly to the mains.

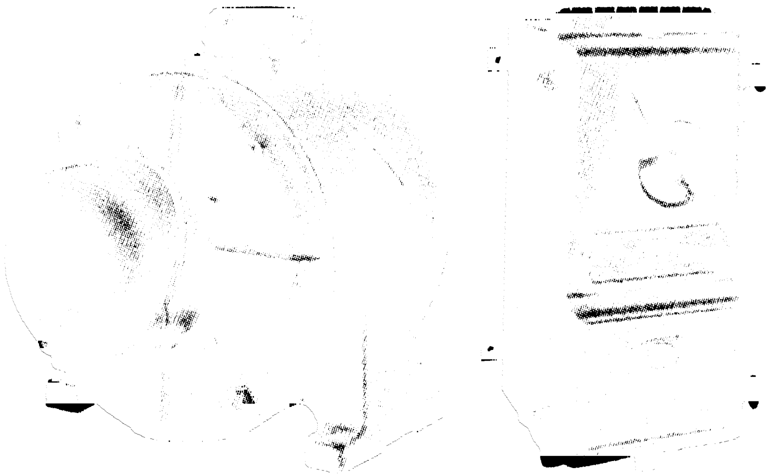

FIG. 15.—TOTALLY ENCLOSED SLIP-RING INDUCTION MOTOR AND STARTER.

By courtesy of the General Electric Co., Ltd.

The starter, unless of the automatic type, may be operated by means of a handle, which should be moved over from the " off " to the " on " position while the motor is gaining speed. With the automatic type of starter the closing of a switch is all that is necessary, the starting process being carried out by an electrically operated mechanism within the starter itself. Fig. 15 shows a starter (with starting handle in the form of a wheel) together with a totally enclosed motor especially suited to operation under arduous conditions.

CHAPTER VII

ELECTRICITY FOR LIGHTING, HEATING, AND DOMESTIC PURPOSES

It is safe to say that, no matter for what purpose a rural consumer may eventually use electricity, in almost all cases its application to domestic uses will be undertaken at the outset, and will always prove to be of great benefit. For this reason domestic electrification will be discussed before passing to the many applications connected with the business end of farming and rural industry. Indeed, it is scarcely correct to separate rigidly the domestic question from the business aspect of farming, since the farm-house serves, in many ways, the dual purpose of a dwelling and an additional " farm building " or " workshop." Especially in the case of the smaller farm, so much of the work of cleaning dairy and milking appliances, the preparation of poultry for the market, and so on, takes place within the farm-house, as well as a much greater amount of cooking for the farm work-people, that it is quite wrong to compare such a house with one of similar size in a town, where the wage-earners are away at business during the greater part of the day and the house is purely a dwelling-place. Again, town houses are very differently situated in respect of heating, lighting, and cooking in that there is often a gas supply as an alternative to electricity, and the houses themselves are usually designed so as to be run much more easily than the average farm-house. Lighting and occasional heating and cooking by oil in country districts, although it has served a useful purpose, cannot be regarded as very satisfactory from the points of view of convenience, cleanliness, efficiency, or even of economy. In addition there are many electrically operated appliances of a miscellaneous character, such as vacuum cleaners, washing machines, fans, refrigerators, etc., which may be of small importance individually, but which, in the aggregate, place a very different complexion upon the work of running the country house.

Most electricity supply authorities are now alive to the fact that the domestic load in rural districts is worth while developing, and methods of charging are adopted which encourage the installation of additional electrical appliances. The author has little hesitation in saying that most country dwellers will find it profitable to take an electricity supply for lighting purposes, while many will find that a cheaper rate is available if they are prepared to assist the supply company by installing such equipment as electric cookers or water heaters.

Lighting

The advantages of electricity for lighting purposes are :

(*a*) *Convenience.*—No cleaning or filling is required as with oil lamps, and the light is immediately available, at any time, at the turn of a switch. Again, the electric lamps can be installed in many situations such as cupboards, passages, larders, etc., in which the use of oil lamps would be either impossible or undesirable.

(*b*) *Efficiency.*—The light obtained is much greater than that from the average oil lamp.

(*c*) *Healthy.*—No undesirable fumes are given off by electric lamps, and under this heading may also be mentioned the eye-strain which is often caused by inefficient lighting.

(*d*) *Safety.*—There is no question of upsetting an electric lamp with the consequent fire risk which is always present with oil lamps.

(*e*) *Appearance.*—With the development of electric lighting has appeared a very large range of really beautiful lighting fittings, giving lighting effects such as no other form of illumination can produce.

(*f*) *Cheapness.*—The costs of electric lighting are discussed below.

Electric Lighting Costs

It must be understood at the outset that the cost of wiring the house initially for an electricity supply cannot well be included in calculating the running costs either of lighting or of the other applications of electricity dealt with in this and succeeding chapters. The costs of installation will be discussed separately later, but these, when averaged over the number of years for which the wiring will last and also between the various appliances used, will be found to have a negligibly small effect upon the running costs of the lamps and other devices.

There is a large range of electric lamps varying in power consumption from 5 watts to several hundred watts. The cost of running, per hour, depends, of course, directly upon this power consumption ; thus, the cost per hour is obtained by dividing the wattage of the lamp by 1,000 and then multiplying by the price of 1 unit of electricity. For example, if electricity costs 1*d*. per unit, a 100-watt lamp costs $\frac{1}{10}$*d*. per hour to run. This cost will be $\frac{2}{10}$*d*. per hour at 2*d*. a unit, and so on. It is often easier to consider the number of hours of light obtainable for the cost of 1 unit of electricity, whatever that may be in any particular district. This was done for a number of different wattages in Table XVI.

Although very low power lamps are available and are useful and very cheap to run for situations such as passages and cupboards, where a dim light is sufficient, wattages between 25 and 100 are necessary in the main rooms. Thus, a 75- or 100-watt lamp is necessary in fairly large rooms (say above 12 × 12 feet), a 60-watt lamp being often sufficient in smaller rooms. For bedrooms even 40-watt lamps may be found sufficient, although it may be desirable to have more than one in each room for alternative use, such as one for a dressing-table and another for general lighting or a bedside table. It is not advisable to install low-power lamps in kitchens and sculleries, although this is a fairly common practice. It is obviously as desirable to have a good light for the work to be done in kitchens as for the enjoyment of leisure time in the other living-rooms. For general lighting in rooms in which work is carried out, the wattage of the lamps used should be sufficient to give $\frac{2}{3}$ to $\frac{3}{4}$ watt per square foot of floor space. Thus, taking a room 15 × 10 feet, a 100-watt lamp should be used (taking the $\frac{2}{3}$ figure). A small-power lamp may be useful to give local lighting for purposes such as sewing, when a more intense illumination is required. It should be noted in this connection that a single lamp placed in the centre of the room is not always the most satisfactory method of lighting. Much of the light so produced is wasted in illuminating walls and ceilings, whereas several smaller lamps, either in the form of reading lamps or mounted on the walls, will give a more satisfactory illumination. The wattages of lamps mentioned above refer to the case of direct lighting, i.e. when the light is allowed to fall directly on the floor space. If bowl fittings are used so that the illumination is obtained by reflection from the ceiling—giving a softer and possibly more decorative effect—increased wattages will be required. The avoidance of " glare " by using such fittings, or, without them, lamps of the " Pearl " or " Opal " type, is very important in reducing eye-strain, and the slightly reduced efficiency of these lamps as compared with " clear-glass " lamps does not counterbalance this advantage.

As regards the actual costs of energy for house lighting, the consumption may vary from about 2 units per week in the case of a small cottage to 5 units or more in the case of a farm-house. In the latter case the consumption may be made up as follows :

One 100-watt lamp for 30 hours per week .	Total weekly consumption, 3 units.
One 60-watt lamp for 30 hours per week .	Total weekly consumption, 1¾ units.
One 40-watt lamp for 15 hours per week .	Total weekly consumption, ½ unit.
One 25-watt lamp for 10 hours per week .	Total weekly consumption, ¼ unit.

This gives a total weekly consumption for lighting of 5½ units, and may be taken as an average throughout the year. It is not intended to imply that only one 100-watt lamp, one 60-watt lamp, etc., are installed, but that the consumption by the 100-watt lamps would amount to 30 lamp-hours per week and so on. At an average energy cost of 1*d.* per unit, the weekly cost would thus be 5½*d.* in this case, or 2*d.* to 3*d.* per week in the case of the small cottage.

Taking the alternative of lighting by paraffin lamps, for the same lighting service as given by the electric lamps considered above, the average consumption of paraffin throughout the year would be about 2 gallons per week at (say) 10*d.* per gallon, or 1*s.* 8*d.* per week. On this basis it would pay to use electricity, provided its price were below 4*d.* per unit, even if one does not consider the saving of time in cleaning and trimming the oil lamps.

As regards the capital cost of the lamps themselves, although they can be bought at 1*s.* each, or even less, the best lamps—the use of which is to be recommended—cost from 1*s.* 9*d.* to 2*s.* 6*d.* according to wattage. Their " life " may be taken at 1,500 hours, so that the hourly cost on this account is only about $\frac{1}{50}$*d.* This might add 1*d.* per week to the lighting cost in the example detailed above, but it is questionable whether it would amount to so much as this, and, in any case, this is offset by the cost of the necessary replacements to oil lamps.

That the above figures are of the right order may be confirmed by an examination of the annual costs for lighting (by methods other than electric) for 42 farms as published in the *Electricity Commissioner's Report on Electricity Supply in Rural Areas* (1928). The costs data were supplied by the National Farmers' Union, and vary from £3 or £4 to about £20 (excluding one or two cases in which the costs were either exceptionally small or very large). These figures correspond to weekly costs of from about 1*s.* 6*d.* to 8*s.*, but include the cost of lighting in the farm buildings.

Electric Cookers

Disregarding, for the moment, the question of costs, the advantages of cooking by electricity are, briefly:

(*a*) *Cleanliness.*—There are no disagreeable fumes or soot coming in contact with the food, since electricity produces its heat without actually burning fuel, and also the cooker itself is designed so that it is easy to remove all stains and splashes from the food cooked.

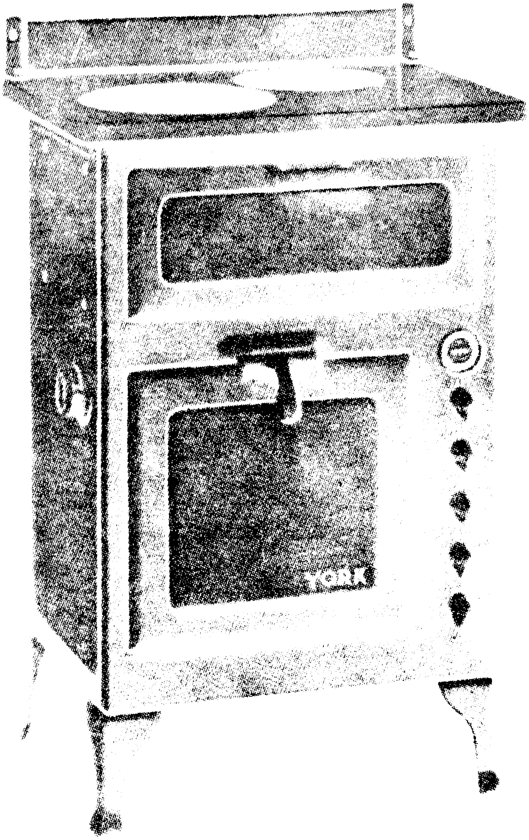

Fig. 16.—" York " Electric Cooker.
By courtesy of Eaton Canadian Products (England) Ltd.

(*b*) *Convenience and Reliability.*—The heat is produced merely as the result of turning a switch, and is available immediately at any hour. In addition, this heat is very easily controlled to give different temperatures according to the cooking requirements.

(*c*) *Health.*—Since the heat is produced within the cooker itself, and is only transmitted very slowly to the surroundings, the kitchen remains very much cooler than when a large fire is made up for cooking purposes.

(*d*) *Economy.*—It is found that there is much less shrinkage in the case of electrically cooked foods, such as meat, and the cooking is more uniform. The saving on this account may be as much as 20 per cent. by weight. In addition, the juices are retained to a greater extent in electrically cooked meat, and this results in an improved flavour.

Construction of Electric Cookers

There are many different makes of cookers, but these do not vary greatly as regards the general construction. The commonest

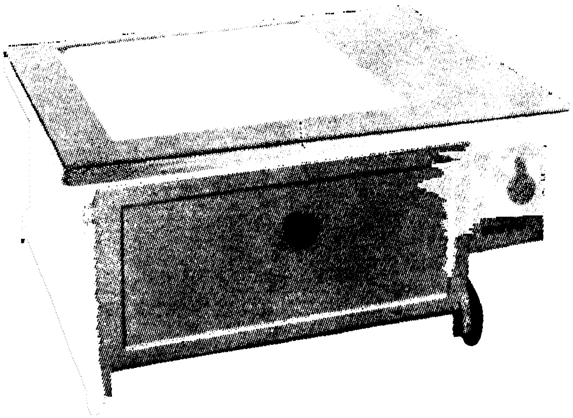

FIG. 17.—BREAKFAST COOKER.
By courtesy of Belling and Co., Ltd.

form, suitable for general cooking for several persons, has: an oven, varying in size from about 12 × 12 × 12 inches (for 4 to 5 persons) to 16 × 16 × 18 inches (for 8 to 12 persons); a grilling and hot cupboard space; a grill; and either one, two, or three hotplates for boiling purposes. The oven, grill, and hotplates are controlled by separate switches, these usually having three positions, so that " high," " medium," and " low " heats can be obtained. These cookers have an attractive enamel finish, and are designed to have the minimum of projecting parts, so that they are very easy to keep clean. Fig. 16 shows a typical cooker of this type.

In addition to the above form of cooker, a range of smaller, so-called breakfast cookers is marketed. These are suitable for grilling, boiling, and toasting. They are cheap as regards both capital cost (from £2 to £4) and electricity consumption, but are insufficient for general household cooking. Fig. 17 shows the construction of a small cooker of this type, the overall dimensions being $15\frac{1}{2} \times 12\frac{1}{2} \times 7\frac{3}{8}$ inches.

The "thermal-storage" type of cooker [1] is a recent development which has not yet been adopted generally, but which may be of great benefit in solving the problem of profitably supplying electricity to rural districts. It has been pointed out in earlier chapters, when dealing with the question of load factor, that it is much more profitable for the supply company to give a small and constant load rather than one which is heavy for short periods only. The thermal-storage cooker takes a small amount of power continuously throughout the twenty-four hours, the heat produced by this power being stored in a large cast-iron block within the cooker. This block is placed above the oven, so that while the bottom portion of the block heats the top of the oven, the top portion of the block forms a hob or boiling plate. There are two heaters, one being

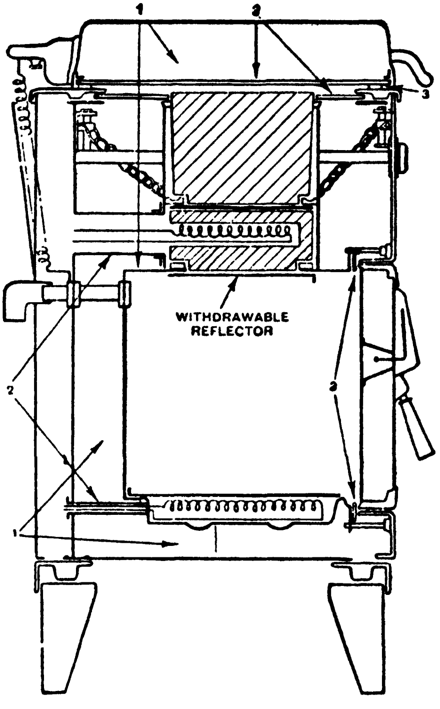

Fig. 18.—Showing Internal Construction of Thermal-storage Cooker.

By courtesy of the General Electric Co., Ltd.

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[1] See *G.E.C. Journal*, vol. III, No. 4, November 1932; vol. VI, No. 4, November 1935.

immersed in the iron block and the other at the bottom of the oven. These are used alternately, so that when the oven is being heated for baking the iron block is not supplied with heat, but gives out some of its stored heat to the oven and to the boiling plate.

During normal running, heat is immediately available for boiling purposes and for casserole or low-temperature oven cooking (the oven being normally at a temperature of about 300° F.), while the extra heat for baking can be obtained by switching over from the block to the oven. A recent modification is the semi-storage cooker, whose continuous loading is only about half that of the "all-storage" type, an increased loading being available for grilling and baking.

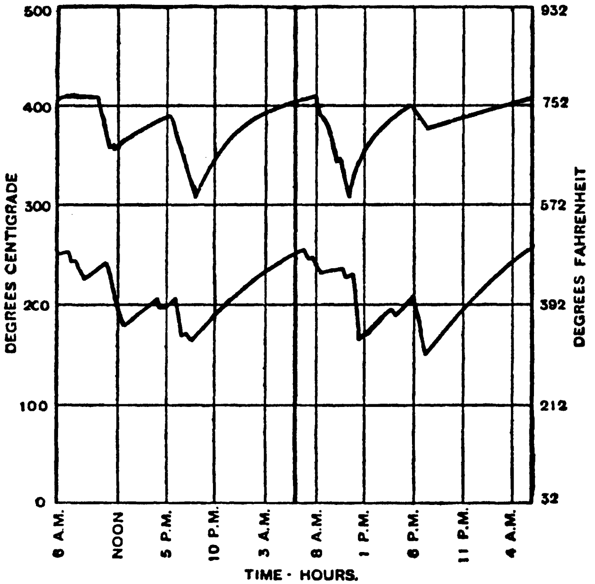

FIG. 19.—TEMPERATURE CURVES FOR THERMAL-STORAGE COOKER.

By courtesy of the General Electric Co., Ltd.

The internal construction of the thermal-storage cooker (all-storage type) is illustrated in Fig. 18. This shows the cast-iron block with its heater and the alternative heater for the oven. The cooker is, of course, heavily lagged with heat-insulating material to prevent the escape of heat from the iron block to the kitchen. A hinged lid, raised when the hob is used for boiling, prevents the escape of heat at the top when the cooker is not in use.

The temperature of the cast-iron storage block falls somewhat as heat is transferred from it to the food cooked, but since the block weighs 165 lb., the amount of heat stored in it is large and the temperature variations are not sufficient to cause inconvenience. In this connection the temperature curves shown in Fig. 19 are of interest. They refer to the temperature of the upper and lower blocks of an all-storage cooker during forty-eight hours, heavy cooking duty being performed in the day-time. The lower curve is for the temperature of the upper block—used for boiling purposes—and shows that this regains its maximum temperature of about 480° F. in readiness for the next day's cooking, the fall in temperature during the day being to about 330° F.

Power taken by Cookers

Ordinary Domestic Type.—The loadings (i.e. wattages) of the different heating elements, when on full heat, are as follows :

Oven	from 1,500 watts to 3,000 watts, according to the size of cooker.
Grill	about 1,500 watts.
Boiling plate (large)	about 1,500 watts.
Boiling plate (small)	about 500 watts.

This makes a total loading, with all the elements on "Full," of from about 5,000 to 8,000 watts.

Breakfast Cooker.—The loading varies from about 750 watts to about 3,500 watts.

The following are average figures for the maximum, or full heat, watts loading per cubic foot of oven capacity or per square inch of surface in the case of grills and hotplates :

Oven	1,100 watts per cubic foot of oven capacity.
Grill	15 watts per square inch of grill surface.
Boiling plate	25 watts per square inch of hotplate surface.

Thermal Storage Cooker:

All-storage type	450 or 500 watts continuously.
Semi-storage type	250 watts continuously, with a maximum wattage of 1,950 watts.

In the ordinary type of cooker, about 1,500 watts per cubic foot of space is needed for heating up the oven, although this may be reduced to about 900 watts when the required temperature has been reached. For boiling plates a wattage of from 20 to 30 per square inch of surface is necessary.

A recent development in connection with electric cookers is the automatic control of the oven temperature. Much experimental work has been carried out on this subject, and there is no fundamental difficulty in carrying out such control. A " thermostat " is incorporated in the cooker, and this device can be set to maintain the oven at any desired temperature. This it does by automatically switching on and off the supply to the heating elements so that the electrical energy consumed is the minimum required to maintain the temperature. As compared with hand regulation by means of the ordinary 3-heat switches, the advantages are a saving in energy consumption and a reduction of the amount of attention required on the part of the cook. Disadvantages are the increased cost due to the necessary thermostat and the modifications of the design of the cooker which are rendered necessary to make such automatic control successful. For thermostatic control to be really successful it is necessary that the oven should have a low reserve of heat, whereas one of the advantages claimed for electric cookers has been that their heat reserve is high, so that cooking may be continued for a considerable time after switching off the supply. Thus, although automatic control can be, and is in some cases, carried out, opinion amongst cooker manufacturers is very much divided as to whether it is worth while. The success of automatic temperature control in gas cookers, however, has done much to popularize this method of cooking and it may be that this fact will render its adoption in electric cookers necessary when these are to be installed in urban districts in which gas is a competitor.

Procedure in Electric Cooking

Oven Cooking.—To prevent loss of the heat produced by the heating elements, the walls of the oven are very efficiently lagged. The heat produced is absorbed in the following ways: (*a*) in raising the temperature of the food to be cooked; (*b*) in raising the temperature of the metal of the oven itself, the air within it, and of the food containers; (*c*) by conduction through the walls of the oven, this conduction taking place very slowly owing to the heat insulation. Only the first of these takes the form of useful heat, and the others must therefore be reduced as much as possible.

The procedure in oven cooking is thus as follows: the oven heating elements are switched on at full heat until the required temperature is reached. This temperature, which is indicated by a thermometer mounted on the oven door, varies with the food to be cooked, and is from about 350° F. to 475° F. The time taken to reach the required temperature may be about 15 to 20 minutes. After putting the food in the oven, the required temperature may be maintained with the heating switches at "medium" or "low" heat. The heat insulation of these ovens is so efficient that they will retain their temperature, to within a few degrees, for about an hour with the heating elements entirely switched off. It is very important to appreciate this to avoid waste of energy. Again, a little planning of the cooking to be carried out will enable advantage to be taken of the fact that the oven temperature is sufficient for the cooking of certain foods for a long period after the main cooking at high temperature is concluded.

The oven door should be opened as little as possible during cooking, as this releases a considerable quantity of hot air and necessitates the heating of the cold air which takes its place.

A pilot lamp is often fitted to indicate when the power is on. This tends to save energy by preventing the power from being left on accidentally.

Hotplate Cooking.—The hotplates are used for boiling purposes. In this case the heating element may be switched fully on until the water in the saucepan is boiling, but, owing to the heat-retaining properties of the boiling plate, the remainder of the boiling may be done with the current switched off.

It is important to use suitable flat-bottomed saucepans on electric hotplates to obtain efficient heating. Unless a uniform contact is made over the whole of the bottom surface of the pan, heating takes place at only a fraction of the total surface, as illustrated in Fig. 20, and this entails waste of heat. Various designs of aluminium utensils have been developed for electric cookers, and expenditure on these may be more than counterbalanced by the saving of energy which they bring about.

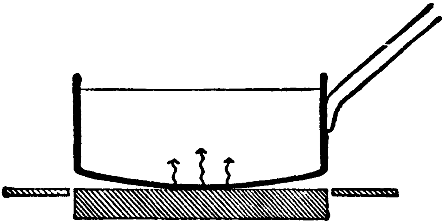

FIG. 20.—SHOWING NON-UNIFORM HEATING DUE TO DISTORTION OF SAUCEPAN.

By courtesy of Hague & Mackenzie, Ltd.

Saucepans for this purpose must have a flat and thick base, and the thickness of the sides must be correctly proportioned in relation to the base to prevent distortion when heated. Their construction is illustrated in Fig. 21, which also shows a twin pan for the purpose of boiling two different vegetables or other foods on one hotplate.

Several forms of quick-boiling hotplates which do not require special utensils have recently been introduced. These are referred to as " open " plates as distinct from the enclosed or " solid " plates referred to above. One type of cooker, whose construction is illustrated in Fig. 22,[1] is fitted with a transformer to convert the normal supply voltage to a low voltage (10 volts) for the boiling plate, which takes a maximum current of 205 amperes. The plate has a 3-heat control giving loadings of 2,250, 900, and 480 watts, is very robust, and is not damaged or short-circuited if the food being boiled spills over. There is practically no time lag with this plate, the heat being available almost immediately after switching on. On the other hand, such plates cool rapidly, so that there is no question of utilizing the residual heat of the plate. A disadvantage of this type of cooker is the increased cost due to the step-down transformer, but this is largely counterbalanced by the saving of the cost of special utensils, and by the fact that the maintenance costs are lower than for other types of plate. The life of both transformer and heating element is very long, and the element may be replaced, when necessary, very easily and at low cost

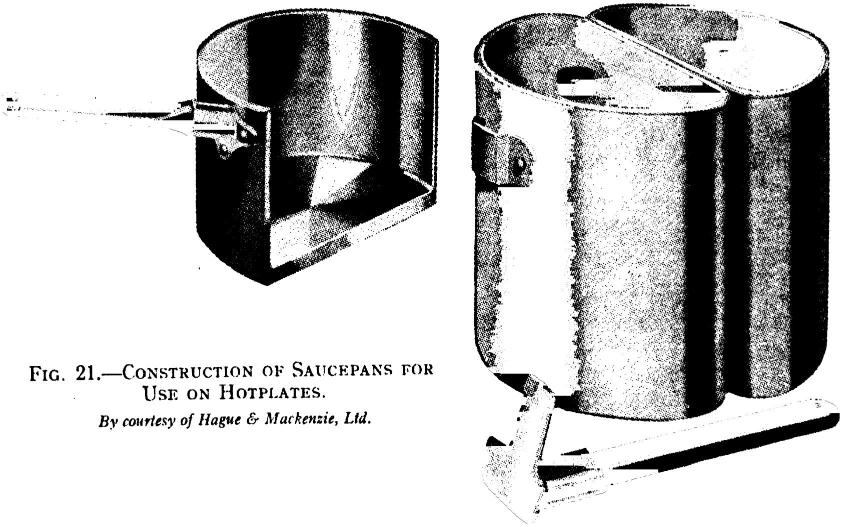

FIG. 21.—CONSTRUCTION OF SAUCEPANS FOR USE ON HOTPLATES.

By courtesy of Hague & Mackenzie, Ltd.

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[1] Manufactured by the Simplex Electric Co., Ltd.

Costs of Electric Cooking

Provided reasonable precautions are taken, on the lines indicated above, to conserve the heat produced, electric cooking competes very favourably with oil cooking when the cost of electricity is 1*d*. per unit or less, apart altogether from the convenience and other advantages, which are sufficient to justify even an increased cost as compared with other methods of cooking. Reliable figures for maximum electricity consumption in electric cooking are: 1 to 1½ units per day per person, the lower figure applying when the number of persons in the family is greater than 3. With increased attention given to the planning of the cooking procedure, the consumption may be reduced considerably.

The consumption in the case of thermal storage cookers is 12 units per day for the all-storage type, since 500 watts are supplied continuously. In the semi-storage type the continuous load is 250 watts, or 6 units per day. This increased consumption may be counterbalanced, however, by a specially favourable rate granted by the supply company for such apparatus.

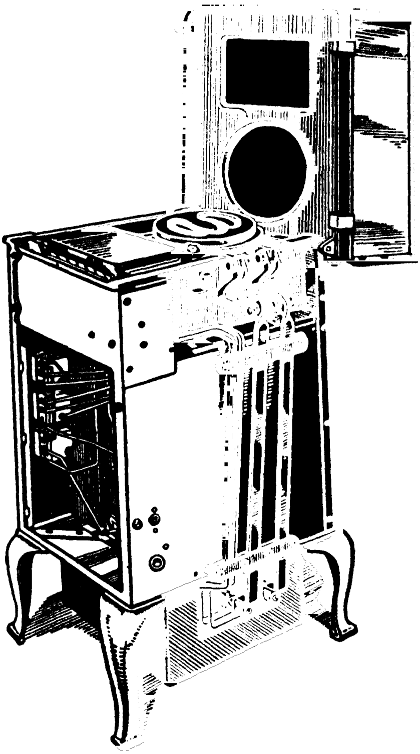

FIG. 22.—SHOWING INTERNAL CONSTRUCTION OF ELECTRIC COOKER WITH TRANSFORMER AND OPEN-TYPE HOTPLATES.

By courtesy of "The Electrical Review."

The following costs, supplied to the author by two unprejudiced consumers who have recently converted from oil lighting and cooking to electricity—in both cases to their complete satisfaction—give a reasonable comparison between the two methods:

Oil Cooking.

Capital cost of cooker (approximate)	£10
Life	8–10 years.
Annual depreciation charge (neglecting interest on capital)	£1
Annual cost of replacement of wicks	10*s*.
Annual fuel charges (average cooking time 2 hours per day, oil 1s. per gallon)	£8
Total annual cost (neglecting labour costs of cleaning, filling, etc.)	£9 10s.

Electric Cooking.

	£	*s.*	*d.*
Annual charge for rent for electric cooker	1	12	0
Average annual charge for electricity for an amount of cooking equivalent to that in the case of oil cooking mentioned above	6	0	0
(The tariff adopted for electricity charges was a 2-part tariff, having a fixed charge based upon the electrical appliances installed, together with a unit charge of ¾*d*. per unit. For the number of units used by these consumers the average price per unit was approximately 1¼*d*.)			
Total annual cost	7	12	0

From these figures it appears that electric cooking is cheaper than oil cooking, regardless of labour costs of cleaning and trimming in the latter case. These costs are quite negligible in electric cooking.

Comparative Costs of Lighting and Cooking together

In the case of a two-part tariff, it is difficult to apportion the fixed charge between cooking, lighting, and other purposes. In the above example the whole of the fixed charge was allotted to the cooking, but this is, of course, unfair, since it makes the cooking costs err on the high side. Figures are available (from one of the consumers mentioned above) for a comparison of the costs of lighting and cooking together by oil and by electricity. These are :

	£	*s.*	*d.*
Oil (per 3 months)	1	16	0
Electricity (per 3 months)	1	5	11

These costs are strictly comparable, since they refer to the same amount of lighting and cooking by the two methods. Both neglect depreciation charges on the cookers. In the case of these consumers, and with the electricity tariffs applying to them, it appears that electricity costs are approximately three-quarters of those applying to the use of oil.

Other Apparatus Associated with Cooking

Water Boilers.—There are three methods of boiling water electrically, namely :

(*a*) By the use of a container standing on a hotplate.

(*b*) By a self-contained electric kettle or other boiling vessel having a heating element fitted under the base of the water compartment.

(*c*) By immersion heaters, i.e. heating elements which are so constructed that they can be totally immersed in the water instead of being fitted under the water compartment, as in method (*b*).

Some interesting results were obtained by Fr. Mortzsch [1] from tests upon these three methods. The tests show that the immersion heater is the most economical as regards the energy consumption. This might be expected, since the whole of the heat generated in the heater must pass directly into the water. The results for two immersion heaters, one of 1,000 watts loading and the other of 700 watts, used to boil 1 litre (1¾ pints) of water contained in an earthenware pot, the initial temperature of the water being 15° C. (59° F.), were :

	Time taken to boil (minutes).	Energy consumption (units).
1,000-watt heater .	6½	$\frac{11}{100}$
700-watt heater . .	10½	$\frac{13}{100}$

This shows that it is more economical to use a quick-boiling heater rather than one of a lower wattage. The material of which the water container is made and its situation influence the energy consumption very considerably ; thus, from the same series of tests, it was found that, under otherwise similar conditions, almost twice as much energy was required to boil water in an aluminium pan standing on an iron surface as to boil the same amount of water by means of the same heater when using an earthenware jug standing on wood. The difference is due, of course, to the heat conducted through the metal pan and base, the earthenware and wood being poor conductors of heat.

Immersion heaters are thus economical, and they are quite convenient for many purposes, but care must be taken to ensure that the heating element is completely immersed before switching on, since they are designed to operate at the maximum allowable temperature when so immersed, and will become overheated—

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[1] *Elektrotechnische Zeitschrift*, March 8th, 1934.

with probable damage—if connected to the supply whilst still in air. Electric kettles may have the heating element fitted under the water compartment, or may be of the immersion-heater type, the latter giving slightly quicker boiling for a given wattage of the heater. The loading of electric kettles ranges from about 500 watts to 2,000 watts, according to size and to the speed with which they are required to boil. The higher loadings give, of course, quicker boiling, but there is little difference in the energy consumption between kettles of similar size and construction but having different loadings.

All kettles must be protected from damage when accidentally allowed to boil dry or when switched on while the kettle is empty. Various methods of protection have been adopted, one of the most convenient being illustrated in Fig. 23 (*a*).

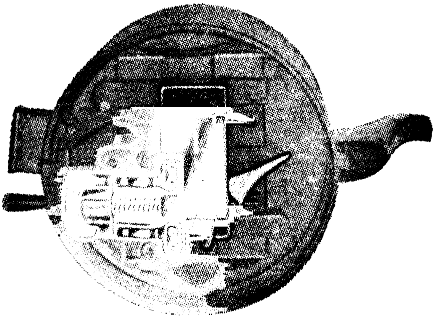

FIG. 23 (*a*).—PREMIER " QUICKSET " KETTLE.

By courtesy of Premier Electric Heaters, Ltd.

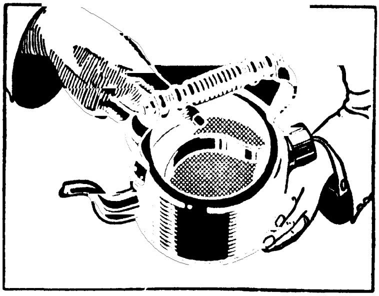

FIG. 23 (*b*).—QUICK-BOILING KETTLE WITH IMMERSION-TYPE HEATER.

By courtesy of Bulpitt & Sons, Ltd.

This shows the under side of the Premier " Quickset " kettle with the protective device in the " open " position taken up when the kettle boils dry. To reset the heater switch it is necessary only to press in again the small projecting plunger at the side after allowing the kettle to cool and having filled it with water. In this kettle the heater is fitted beneath the water compartment. In Fig. 23 (*b*) a quick-boiling kettle having an immersion type of heater is illustrated. Most of these electric kettles have heat-insulating feet to prevent conduction to the surface upon which the kettle is standing.

The time taken, and the energy consumption, when boiling by means of a non-electric kettle or saucepan placed on a hotplate depends upon the initial temperature of the plate. If the plate is already warm when the boiling vessel is placed on it, the time and energy consumption compare reasonably well with those for the two methods of boiling already discussed, but if the plate is cold, heat is required to raise its temperature before the water can be heated. This results in very uneconomical boiling, since much of the heat produced remains in the heated plate when the boiling operation is completed. The energy consumption may be twice as much with a plate initially cold as compared with a pre-heated plate. This emphasizes the necessity for taking advantage of the available heat in hotplates by suitably arranging the cooking procedure.

Lest the reader may have the impression that electric cooking is unduly complicated, one may state simply that it is merely necessary to remember that electrically produced heat represents money (in the electricity bill) and must accordingly be utilized to the full.

The following table gives a comparison between the energy consumptions of the three methods of boiling, in each case referred to boiling 1 pint of water from cold (i.e. tap-water temperature):

TABLE XVII

Type of boiling equipment.	Energy consumption per pint of water boiled. In thousandths of a unit.
Immersion heater	65
Kettle	80
Hotplate (starting warm)	70
Hotplate (starting cold)	108

The figures show that there is little to choose between the three methods of boiling as regards economy, provided, in the case of the hotplate, that the plate is initially warm. Otherwise the hotplate method is uneconomical.

With energy at 1*d*. per unit the cost per pint is thus from $\frac{1}{15}$*d*. to $\frac{1}{12}$*d*.

Boiling Rings.—These are really miniature cookers without an oven or grilling space. They are usually large enough to accommodate two or three saucepans, which can be kept simmering after being brought to the boiling-point singly.

Their wattage may be from 500 to 2,000 watts, with or without two- or three-heat regulation. The capital cost of these boilers is low (usually between £1 and £2 10*s*.).

Warming Plates.—For the purpose of keeping dishes hot on the table—not for boiling purposes—these plates are very useful. Their loading is usually between 100 and 500 watts.

Saucepans and Egg-boilers.—These have a self-contained heating element like electric kettles, the loading being from 250 watts upwards, according to size.

Toasters.—Electric toasters are usually designed for use on the table, and are fitted with a device for turning the bread without handling. They will toast two pieces of bread at once, the loading being about 500 watts in the ordinary domestic sizes.

Coffee Percolators.—Like the toasters, these may be used on the table, and have a slightly lower wattage than the former.

In addition to the above appliances, various small devices, such as waffle-irons, egg-beaters, dish- and glass-washers, and potato-peelers, have been placed on the market. Though not essential, some of these are very useful, and their power consumptions are small. A range of potato-peelers having capacities of from 12 to 38 lb. is manufactured by the Hobart Manufacturing Co., Ltd. These have a self-contained motor of $\frac{1}{4}$, $\frac{1}{2}$, or 1 h.p., and while being, perhaps, too large for domestic use, are well suited to the requirements of hotels, restaurants, and institutions.

Refrigerators

Although refrigerators have long been regarded as a luxury, the greatly extended use of electricity has led to their increased use in provision shops, hotels, and, more recently, in dwelling-houses. Many foods deteriorate in food value, and the growth of dangerous bacteria in them is encouraged, if they are kept at a temperature exceeding about 50° F. In the older houses cellars were provided to give the necessary cold storage, but the largely increased building costs and the demand for cheap houses in recent years have brought about the almost complete elimination of the cellar in houses of ordinary size. The refrigerator, therefore, as the modern counterpart of the cellar, has a very important function.

Until recently the capital cost of refrigerators has been against their general adoption, but there are now so many designs and sizes on the market and also suitable hire-purchase arrangements that the objection can no longer be raised. Indeed, even the most expensive refrigerators now on the market would compare favourably, as regards capital cost, with the alternative (and less efficient) method of building a cellar for food storage, in addition to the fact that they give cooling which is under complete control, are very easily cleaned, and occupy only a very small space.

There are two general types of electrically operated refrigerators for domestic use—one working on the compression principle and the other by absorption.

In the first of these a gaseous refrigerant—usually sulphur dioxide—is highly compressed in a compressor driven by a small electric motor ($\frac{1}{8}$–$\frac{1}{4}$ h.p.), the temperature of the gas being increased considerably during the compression. This gas then passes to an air-cooled " condenser," in which it liquefies. The liquid refrigerant then flows into an " evaporator " consisting of pipes immersed in a solution of calcium chloride (termed " brine "), where it again becomes a gas, and, in doing so, takes heat from—and therefore cools—the brine. The cooled brine circulates through pipes to produce the cooling of the refrigerator chamber itself. An automatic control is generally fitted, so that the motor only commences to run when the temperature exceeds the desired upper limit. In this way the energy consumption is kept small—about 1 unit of electricity per day.

In the absorption type the gaseous refrigerant is dissolved in cold water before passing to a " generator " in which the solution is electrically heated, causing the gas to be given off again. This gas passes to the condenser, where it is liquefied, and thence to an evaporator, in which the cooling is produced by evaporation of the liquid refrigerant as in the compression type. This type has the advantages of complete silence and the absence of any moving parts, but in the larger models of this type water cooling is necessary.

The cabinets designed for domestic use have capacities of from 1 cubic foot to about 20 cubic feet (5 or 6 cubic feet being most usual) the price being from about £20 upwards. The walls are lagged to exclude heat, and the cabinets are lined with porcelain or some other easily cleaned material, the close-fitting doors providing a very effective seal against the entry of dust or insects. In some models an electric light is fitted which illuminates the interior automatically when the door is opened.

The temperature within the refrigerator is controllable, so that the most suitable temperature for the food stored may be obtained. This varies for different foods from about 25° F. to

45° F., although the latter temperature will be found sufficiently cold for many general purposes, and involves a much smaller expenditure of energy than the lower temperatures.

Electric Heating of Rooms

In the author's opinion the general heating of rooms is one of the very few applications of electricity to domestic purposes which cannot fairly be claimed to be cheaper than the alternative methods of performing the same function. It must be admitted that, unless the electricity tariff is very low (½*d.* per unit or less), a coal fire—disregarding gas as being unavailable in country districts—is the cheaper. There must be few who would honestly deny that they prefer the cheery warmth of a coal or wood fire to any other form of room heating, and, in addition, the heat given to the structure of the building and the ventilation produced by the chimney are undoubtedly in its favour. At the same time, coal fires are not convenient at all times or in all situations, and electric heating provides a very efficient and not unduly expensive alternative.

Electric Fires or Radiators.—These are very convenient for occasional or short-period heating of rooms which are not in continuous use, such as bathrooms and dining-rooms, and in situations when a coal fire either could not be used or would entail too much labour to be worth while. For the production of a low degree of warmth for sculleries, washhouses, and similar rooms, and for localized heating, small electric fires are found to be quite inexpensive to run.

The general advantages of electric fires may be summarized as follows :

(*a*) The heat is produced quickly, and can be easily controlled by suitable switches to give any desired room temperature.

(*b*) There is a complete absence of soot and smoke, so that decorations in electrically heated rooms maintain their freshness for a long period.

(*c*) No cleaning or stoking is required and chimney-sweeping is eliminated.

(*d*) The fire may be obtained in a portable form, so that it can be placed in the most advantageous position in the room.

(*e*) The appearance is good.

The electric fire is now so familiar that descriptions of types are unnecessary. The wattage of domestic types varies from a few hundred watts up to 4 or 5 kilowatts, and the price from about 5*s.* up to about £10.

The amount of heat required to maintain a room at any particular temperature depends upon [1]:

The cubic capacity of the room (cubic feet);

The area of wall and ceiling surface which is in direct contact with the outside air;

The material and thickness of the walls;

The area of the windows;

The outside temperature;

The rate at which the air in the room changes, i.e. the amount of ventilation.

The heat loss by conduction per square foot of surface of walls, ceiling, and floor per degree Fahrenheit difference in temperature between the inside and outside of the room may be expressed in terms of units of electricity (kWh) per hour, and is given by $\frac{293}{1,000,000}$ multiplied by a factor which varies from $\frac{1}{10}$ for thick brick walls to 1 for a window of single thickness.

Thus, if the temperature difference between inside and outside is 30° F., the loss through a window 7 × 4 feet would be: $7 \times 4 \times 30 \times \frac{293}{1,000,000} \times 1$ kWh per hour, or about ¼ unit per hour.

Similar calculations can be made to obtain the loss of heat through the walls, floor, and ceiling by taking the appropriate factor, a general average value of this constant being ¼.

Again, 1 cubic foot of air requires about $\frac{6}{1,000,000}$ unit of electricity to raise its temperature 1° F. The air in a room changes at a rate which is found, in general, to vary with the size of the room, and, of course, upon the ventilation, that in a public room with doors constantly opening being much higher than in a private closed room. For ordinary domestic rooms the air may be considered to change completely twice per hour, so that the units of electricity needed per hour on this account are given by multiplying twice the cubic feet capacity of the room by the temperature difference between inside and outside (° F.) and by $\frac{6}{1,000,000}$. For a room 20 × 15 × 10 feet, the electrical energy required on this account, for a temperature difference of 30° F., would thus be about 1 unit per hour.

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[1] For detailed discussions of this question see *Electric Heating*, by E. A. Wilcox (McGraw-Hill), and *The Engineering Equipment of Buildings*, by A. C. Pallot (Pitman).

The total heat required to maintain the room temperature is, of course, the sum of that lost by conduction and that lost by the changes of air in the room.

A rough rule for the determination of the wattage required is to allow from $\frac{3}{4}$ to $1\frac{1}{4}$ watts per cubic foot of space in the room. Thus, taking 1 watt per cubic foot, a room of dimensions 20 × 15 × 10 feet (i.e. 3,000 cubic feet) would require 3,000 watts, or 3 kilowatts.

It is usually found that this wattage is only required to heat up the room initially, after which one or two elements of the fire may be switched off.

Tubular Heaters.—In addition to electric fires, discussed above, which operate at a sufficiently high temperature to cause them to glow (radiant heaters), lower-temperature tubular heaters are being increasingly used for the continuous heating of rooms—more particularly workrooms, churches, shops, and institutions. These are somewhat similar in design and appearance to the familiar hot-water pipes used for the same purpose, the hot water being replaced by wire-wound heating elements. The operating temperature usually lies between 120° F. and 160° F. above that of the surrounding air, and the necessary heat is provided by a much larger heating surface than that in electric fires.

Tubular heaters are essentially "convection" heaters, and their purpose is to warm the air in the room rather than to dissipate the heat by direct radiation. The principal advantage of this method of heating is that the temperatures in the various parts of the room are much more uniform than those obtainable with any form of radiant heater or fire. The heat is, however, not so quickly available as with the latter, the maximum temperature of the tubes being attained only after about 20 minutes (with the normal loading of about 60 watts per foot run). The heating tubes are mounted either singly or in banks of two, three, or four tiers, these being placed either round the walls of the room, under windows, or, in some cases, on beams under skylights. They may also be recessed below the floor and covered with perforated gratings.

To obtain efficient heating of the air in the room, it must be brought into intimate contact with the heating tubes. In this connection the design of the Maxheat Oval Tubular Heater[1] (see Fig. 24) is of interest. The oval section of the tubes causes over 90 per cent. of the surface to be swept by the ascending air as against only 60 per cent. in the case of a round tube. This allows

[1] Manufactured by the Wardle Engineering Co., Ltd.

a lower working temperature to be used for the same amount of heat supplied to the air of the room, the makers claiming that a loading of 60 watts per foot with this shape of tube is equivalent to 80 watts per foot with a round tube.

These tubes are manufactured with loadings of 60 watts, 70 watts, or 80 watts per foot run in the smooth types, gilled tubes, having loadings of 150 to 200 watts per foot, being available for situations requiring a large heating capacity.

For economy in consumption, "thermostats" may be installed to ensure that the consumption is the minimum required to give a steady temperature of any desired value.

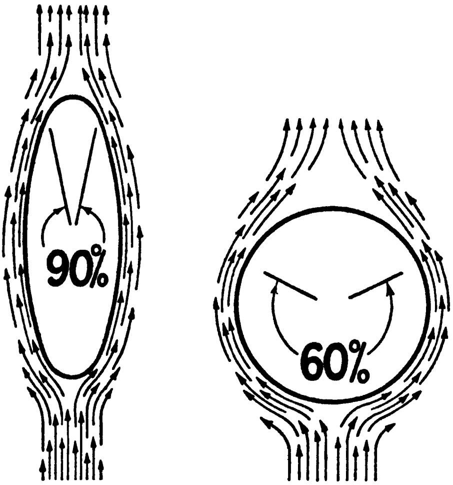

FIG. 24.—COMPARISON OF OVAL AND CIRCULAR SECTIONS.

By courtesy of Wardle Engineering Co., Ltd.

These thermostats may be regulated to within 1½° F.

A few instances of suitable room temperatures are given below :

	Degrees Fahrenheit.
Domestic living-rooms	60–65
Entrance halls	50–60
Bathrooms	70
Bedrooms	50–55
Offices	60
Schools	60
Churches	55–60
Shops	55–60
Factories	50–55

Tubular heaters are also suitable for greenhouse heating, for which purpose the thermostatic control, maintaining a steady temperature, is very convenient. Temperatures required vary, of course, with the types of plants to be raised, and range from about 40° F. to 80 or 90° F.

The length of tubing required for any particular room may be obtained by dividing the estimated total watts loading required for the desired temperature by the watts loading per foot run. the total loading being obtained as below :

Total Watts loading = Floor area in square feet × Temperature difference (in ° F.) between inside and outside × K.

K is a factor the value of which depends upon the size and shape of the room, and may be obtained from the following table [1] :

TABLE XVIII

Height of room in feet.	Floor Area in Square Feet.										
	100	200	300	400	500	600	700	800	900	1,000	
8	·338	·336	·330	·324	·316	·308	·295	·288	·274	·255	·234 above 1,000 sq. ft
9	·360	·357	·351	·343	·334	·325	·312	·297	·277	·253 above 900 sq. ft.	
10	·397	·376	·368	·349	·348	·335	·321	·297	·270 above 800 sq. ft.		
11	·398	·393	·383	·372	·353	·340	·334	·296 above 700 sq. ft.			
12	·415	·414	·405	·393	·378	·350	·346	·321 above 700 sq. ft.			
13	·432	·427	·414	·400	·380	·360	·337 above 600 sq. ft.				
14	·449	·448	·436	·420	·400	·372	·363 above 600 sq. ft.				
15	·466	·458	·440	·420	·391	·373 above 500 sq. ft.					
16	·480	·476	·460	·438	·408	·394 above 500 sq. ft.					
18	·509	·496	·473	·441	·435 above 400 sq. ft.						
20	·538	·533	·508	·475	·461 above 400 sq. ft.						

Example : (*a*) A room 20 × 15 × 10 feet (height).
(*b*) A room 50 × 40 × 20 feet (height).

Suppose a temperature difference between inside and outside of 30° F. is required in each case and that tubing having a loading of 80 watts per foot is to be used. Then, in case (*a*) :

Total watts loading = (20 × 15) × 30 × K = 300 × 30 × K.

From the table (line 3, column 4) K = ·368.

Thus, the total loading required is 300 × 30 × ·368, which is 3,320 watts, and the length of tubing $\frac{3,320}{80}$ feet, or 41½ feet.

In case (*b*) the floor area is 2,000 square feet, so that the appropriate value of K is obtained from line 11, column 6, and is ·461.

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[1] Supplied by the Wardle Engineering Co., Ltd.

$$\text{Total watts loading} = 2{,}000 \times 30 \times \cdot 461$$
$$= 27{,}700 \text{ watts (i.e. } 27\tfrac{3}{4} \text{ kilowatts).}$$

The length of tubing required would thus be $\frac{27,700}{80}$ feet, or 346 feet.

It is interesting to note that the values of watts per cubic foot of space in these two cases are $\frac{3,320}{3,000} = 1{\cdot}11$ and $\frac{27,700}{40,000} = {\cdot}69$, or about 1 watt per cubic foot and ¾ watt per cubic foot respectively. These figures agree very well with the rough rule mentioned on p. 124.

The following table [1] gives approximate values of the annual energy consumption in various types of buildings heated by tubular heaters. The consumptions are given in units per annum per kilowatt installed. Thus, if the consumption is 1,000 this implies that the installation is in full use for the equivalent of 1,000 hours per annum.

TABLE XIX

Building.	Units per annum per kilowatt installed.
Churches (Sundays only)	150– 200
Churches (Roman Catholic)	300– 400
Schools (60° F.)	550- 600
Schools (55° F.)	450– 500
City Offices (60° F.)	900– 950
Shops (60° F.)	1,000–1,100
Factories (55° F.)	850– 900
Theatres and Cinemas (2.30 p.m. to 10.30 p.m.)	450– 500
Theatres and Cinemas (7.30 p.m. to 10.30 p.m.)	250– 300
Technical Colleges (60° F.)	800– 900

As an illustration of the use of the above table in calculating the annual cost of electricity for heating purposes, consider the heating of a shop with an installed capacity of 4 kilowatts. From the table the consumption in this case is 1,000 to 1,100 units per kilowatt installed, which will thus give 4,400 units per annum if we take the higher value of 1,100. The electricity tariff for heating purposes is often lower than that for other purposes, so that we shall be justified in taking ¾*d.* per unit as the charge.

The annual bill in this case will therefore be (4,400 × ¾) pence, or £13 15*s.*

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[1] Supplied by the Wardle Engineering Co., Ltd.

Panel Heating.—This is a method of low-temperature heating which is alternative to the tubular heaters discussed above. A large variety of types of panel heaters is available, but all are in the form of flat panels which can be fixed to or hung on the walls of the room or attached to the ceiling, the wires of the heating element itself being invisible.

Several manufacturers make heaters which are intended to cover the whole of the ceiling of the room, one of these—by the Dulrae Manufacturing Co.—consisting of a special fabric with embedded heating wires, this being attached to the ceiling by a special adhesive.

The watts loading varies considerably with the type, that for the ceiling types just mentioned being, naturally, lower than that in the case of the small panels for attachment to walls for which the loading is of the order of 80 to 100 watts per square foot.

Small Heating Devices.—Before leaving the question of electric heating, two or three of the smaller, special-purpose devices, such as towel-rails, hair-dryers, and electric blankets or bed warmers, are deserving of mention.

Towel-rails are usually fitted in bathrooms, and give a gentle heat sufficient to dry the towels. The watts loading is low—50 to 500 watts, the larger sizes being combined towel-rails and bathroom heaters—and an earthing terminal is often provided, so that all exposed metal parts may be in electrical connection with earth to prevent shocks, this being specially important in the case of all electrical apparatus used in bathrooms.

Hair-dryers contain a small motor-driven fan and a heater, so that a stream of hot air is blown on to the hair. There are usually three positions of the switch, one of which enables the fan to be used without the heater, so that a stream of cold air can be used to restore the scalp to normal temperature after the drying process. The watts loading is about 600 watts.

Electric blankets or bed warmers contain flexible heating elements having a low wattage (from 60 to 500 watts), and are very useful for airing beds or in cases of illness. Their cost varies with size and type from about 15*s.* to £3.

Fans.—To keep rooms cool in hot weather fans are very efficient, and cheap both in initial and in running costs, while their use is almost essential in certain types of public rooms, such as cinemas, restaurants, and the like.

For small-power purposes, such as domestic use, fans are usually of the propeller form, and may be either permanently fixed in a wall vent (when they are referred to as "exhaust" fans), attached to the ceiling, or may be of the portable or desk type. Self-closing louvres or some alternative device should be fitted in the case of exhaust fans to prevent air blowing into the room when the fan is not in use. Otherwise the fan may attain a considerable speed in the reverse direction to that when running under power, so that the motor may be damaged if switched on under these conditions.

The smaller domestic-type fans can displace from 100 to 1,000 cubic feet of air per minute, according to type and size, and take from 20 to 100 watts, their capital cost being from about £1 upwards.

In most situations a guard is necessary to prevent the fan blades from being touched accidentally while running. The " Bandolero " fan dispenses with the necessity for a guard, since, instead of metal blades, the revolving parts or blades are of specially woven fabric and can be touched, while revolving, without danger.

Water Heating.—Another important application of electricity for domestic purposes lies in the production of hot water. In addition to the ordinary domestic uses hot water is, of course, very necessary in rural districts for many purposes, such as for food mixing on stock-rearing farms, cleansing utensils in dairies, and so on. This application forms, therefore, a potential load of considerable magnitude, and rural electrification authorities are usually willing to supply power for this purpose at a favourable rate, especially if the apparatus installed is arranged to improve the load factor by using power either continuously or at times other than those of the maximum load on the system.

From the consumer's point of view water heating by electricity either as an auxiliary to an existing coal-heated system, or in the form of a self-contained heating unit, is inexpensive and very satisfactory, provided adequate consideration is given to the choice of the most suitable form of heater. Several types will be mentioned later, but as a preliminary it is well to consider a few elementary facts regarding the consumption of power and energy for such heating.

On the assumption that there is no loss of heat whatsoever from the hot-water tank or pipes, the electrical energy required to raise the temperature of 1 gallon of water from, say, a cold temperature of 50° F. to a temperature of 165° F. (boiling-point is 212° F.) is almost exactly one-third of a unit (or kilowatt-hour). With electricity at ¾*d.* per unit, therefore, the cost of heating, neglecting heat losses, is ¼*d.* per gallon if the system is all electric, no coal or other fuel being used in addition. The cost is, of course, greater or less according as the temperature rise required is greater or less than 115° F. (as taken above).

As regards the power (wattage) required in the heater, this depends upon the rate at which hot water is used. In practice the question is complicated by the many possible variations in the use of the hot water, e.g. whether a small quantity is used almost continuously or whether large quantities are required at infrequent intervals. If we take the simplest case, and consider utilization at a steady rate of 1 gallon per hour, this, as seen above, will require ⅓ unit per hour (or 333 watt-hours per hour). The wattage required would thus be 333. If 2 gallons per hour were used, 666 watts would be necessary, and so on in proportion to the quantity used per hour.

If these facts are borne in mind, a consumer may rapidly estimate the cost of heating in his particular case, and, although the method of utilizing the water suggested above may be very artificial, the wattages mentioned in this instance should enable the reader to appreciate the fallacy of expecting a heater of a few hundred watts capacity to heat satisfactorily a large hot-water tank which is in continuous use.

Types of Water Heaters

There are two general classes of water heaters, namely, (*a*) Instantaneous, or "Geyser," heaters and (*b*) Storage heaters, the second being the more important, and including a large number of different types.

Electric Geysers.—The action of the electric geyser is similar to that of the gas geyser, with which most people are now familiar. The water is heated almost instantaneously as drawn off, no heating preliminary to use being necessary. The heater is switched on at the same instant as the water tap is opened, and the temperature of the water emerging is governed by the rate at which it is allowed to pass through the geyser and upon the watts loading of the heater.

The advantages of this form of heater are its simplicity and very small maintenance costs, the small space occupied by it, and the absence of any heat losses when not in use. The most serious disadvantage is the very high wattage required if the rate of production of hot water is to be other than very slow. This will be appreciated from the remarks in the preceding paragraph, where it was shown that 333 watts loading is necessary for the very small flow of 1 gallon per hour. Thus, for example, since a bath would require about 12 gallons of hot water at 165° F. (the temperature considered in the previous paragraph), to obtain this in 1 hour would require a loading of 12 × 333 watts, or 4 kilowatts. One hour is much too long to take in filling a bath, however, so that we may take 12 kilowatts as being required to produce the hot water in 20 minutes. Actually 8 kilowatts is the minimum requirement for bath purposes, while 5 kilowatts is the standard loading for small geysers for wash-basins and the like. This high loading is very undesirable, since it tends to produce a low load-factor, and also the heavy current taken causes large voltage drops in the supply mains unless these are of ample proportions. For these reasons geyser-type heaters are not well suited to use in rural districts.

Storage Heaters.—Instead of having a high loading with almost instantaneous heating, the majority of the electric water heaters in use employ a heating element of much lower loading than those mentioned above, the element being in circuit for a much longer time to produce the required hot water. Storage of the heat produced, for a time which depends upon the type of heater considered, is thus essential, and the question of effectively lagging the tank to prevent heat losses becomes vital if economical working is to be obtained.

It is impossible, in the space available here, to discuss in detail the various storage systems in use, and the reader requiring more information on the subject is referred to such specialized books as *Electric Water Heating*, by Bolton, Honey, and Richardson, which gives a comprehensive review of the whole question. The form of heater best suited to a consumer's requirements depends upon so many variable factors, such as the rate of using hot water, the number of points to be supplied with it, the existence or otherwise of a fuel-heated system and its layout, that the non-technical consumer will be wise to consult the representatives of the local supply authority before deciding upon any particular form of heater.

Storage heaters may be divided very broadly into two categories, namely:

(*a*) Heaters which are designed to give a supply of hot water independently of any fuel-heated system.

(*b*) Heaters which are intended for use in conjunction with a fuel-heated system.

(*a*) Those of the first class are manufactured in standard sizes as follows:

1½, 3, 5, 12, 15, 20, 30, 40, and 60 gallons, the corresponding standard loadings of the heating elements being :

	Watts.
For 1½, 3, and 5 gal.	500
12 gal.	1,000
15 gal.	1,500
20 gal.	2,000
30 gal.	2,500
40 and 60 gal.	3,000

The majority of such heaters are fitted with a thermostat, which can be adjusted to cut off the supply when the water temperature reaches any desired value (usually between 140° F. and 190° F.), and to cut in again when the temperature falls some 10 or 15° F. These heaters must be effectively lagged during manufacture to reduce heat losses from the tank during storage. The losses amount to about 0·04 watt per square foot of outside surface per degree Fahrenheit rise in temperature of the water. Taking the normal size of such heaters and an average thermostat setting, the tank losses per week will be equivalent to from 6 to 7 units of electricity in the case of the 5-gallon heater, and about 15 units for the 20-gallon size. This energy expenditure must be looked upon as the cost of a hot-water service which provides an immediate supply of hot water at any time. Whether this energy consumption can be afforded depends upon the magnitude of a consumer's hot-water requirements and upon the cost of energy in his particular district.

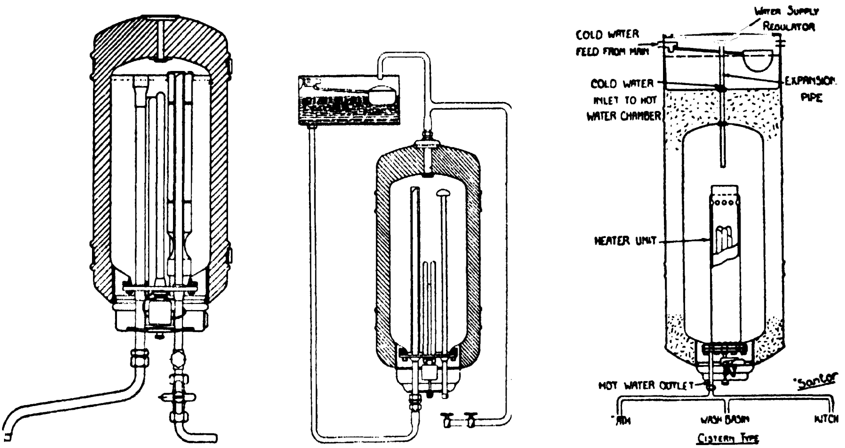
The 1½-, 3-, and 5-gallon sizes are sufficient for wash-basin or kitchen duty, while to provide water for baths 12 gallons is the minimum size.

The three common types of such heaters are :

(i) The Displacement or Non-pressure type, used to supply hot water at one point only. A heater and thermostat are fitted at the bottom of the tank, and upon opening the cold-water inlet at the base, the hot water is displaced from the top of the tank. Both a baffle, to prevent the cold water entering the tank from mixing immediately with the hot water, and an anti-drip device to prevent dripping—and therefore waste of hot water—due to expansion, are fitted. A swivelling discharge pipe is often used, so that when the heater is fitted adjacent to both a wash-basin and bath, a supply can be given to either. This type has the advantages of simplicity both in construction and in installation and of the absence of heat losses in pipes conveying hot water to distant points.

(ii) The Pressure type, which gives a supply, through pipes, to several points, and is similar, as regards installation, to the ordinary domestic fuel-heated system. The heater itself is very similar in construction to the Displacement type, having a heating element, thermostat, and lagging. There may be considerable losses in the hot-water pipes if the tank is situated at a distance from the points to be supplied.

(iii) The Cistern type, which again is intended for supply to several taps. This has a self-contained cold-water cistern and ball-valve, and can be connected directly to the cold-water supply main.



(i) (ii) (iii)

FIG. 25.—SHOWING THE CONSTRUCTION OF THE THREE TYPES OF STORAGE WATER HEATERS.
By courtesy of Santon, Ltd.

The construction of these three types of heaters is illustrated in Fig. 25.

In addition to the above, which are intended to be left continuously connected to the electricity supply and are thermostatically controlled, an unlagged heater, without a thermostat, is manufactured. This is for occasional use, for such purposes as baths, and is switched on an hour or so before use and then switched off. This is a simple and economical heater, but its application is limited.

The capital cost of heaters of the above types varies, according to size, from about £5 to £40, but in many cases these may be hired from the electricity supply authority, the hire charges varying from about 3s. to £1 per quarter.

(*b*) The heaters described above, although they may, of course, be used together with a fuel-heated system, are essentially self-contained heaters, and are more commonly installed in new buildings or are used to replace an existing system. An alternative which has a very wide field, especially in rural districts, consists in the installation of some form of electric heater, either in or around the existing hot-water tank, as an auxiliary to the fuel-heated system.

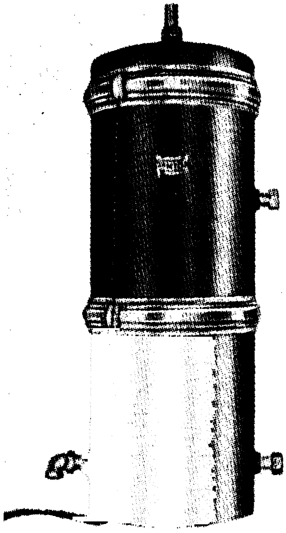


FIG. 26.—SANTON BELT-TYPE HEATER.

By courtesy of Santon, Ltd.

This usually involves piercing the tank and inserting either one or two heaters, often with a thermostat in addition, although a belt form of heater, illustrated in Fig. 26, is available. This can be clamped round the outside of the tank and avoids piercing. This method of heating is cheap as regards first cost, since the immersion heaters used are cheaper than the complete heaters described in the preceding section, and, when hired, the quarterly hire charges are less. They are not so economical for continuous connection with thermostatic control, since, although the hot-water tank can and should be lagged, it is impossible to do this as effectively as in the case of the self-contained storage heaters, so that the heat losses from the tank are higher and may render the heater expensive in operation.

Various methods have been introduced to reduce the losses, and economical operation can be obtained, but continuous connection, with thermostatic control, is in most cases prohibitive in cost. The alternative methods of dealing with heating under these conditions are briefly as follows :

(i) Immersion heater, fitted either vertically or horizontally in the tank. In the former case the heating element may be designed so as to have a greater loading density (watts per square inch of surface) at the bottom than at the top. In the latter case two heaters, fitted at different levels in the tank, may be used in conjunction with a three-heat switch, so that only a small quantity of water may be heated if desired instead of the whole of the tank contents. This reduces both energy consumption and heat losses from the tank.

(ii) A circulator of either the immersion or external type. These pass the water, when heated, directly to the top of the tank ready for use, instead of allowing more general circulation with consequent heating of the whole of the tank content. They thus make for rapid recovery after the withdrawal of a large quantity of hot water.

Thermostats are commonly fitted with both of the above types of heaters, but these are more for the purpose of cutting off the supply if the heater should be accidentally left in circuit than for providing any continuous regulation. In brief, immersion heaters are principally useful as boosters augmenting the hot-water supply rather than as a continuous source of hot water. With judicious switching to ensure that they are used only when actually required, they are both economical and convenient.

The construction of immersion heaters and of immersion- and external-type circulators is shown in Fig. 27. The external circulator is suitable only for soft water. Illustration (*a*) of this figure is of a four-bladed immersion heater whose advantage is that it has a high loading (4,000 watts) in a small space (10 inches length). Illustration (*b*) is of an immersion heater having a removable core for ease of replacement without disturbing the contents of the tank. The heating core fits inside a solid-drawn copper or steel tube, which is a permanent fixture in the tank.

The watts loading of immersion heaters must be chosen, as previously discussed, in accordance with the size of tank with which they have to deal.

Energy Consumption in Water Heaters.—As already pointed out, the energy consumption for the actual heating of the water is about $\frac{1}{3}$ unit (kWh) per gallon. To this must be added the consumption due to heat losses from the tank and hot pipes if a storage system is used, but these may be neglected if a system is used in which the heater is switched on only for comparatively short periods of time. When an electric heater is used in conjunction with a fuel-heated system, the heat supplied by the former is often only a small part of the total heat in the water, and the consumption will be much less than $\frac{1}{3}$ kWh per gallon.

The annual consumption of electricity on account of water heating depends, of course, upon the system used, the size of the establishment, and the consequent utilization of hot water. Where most of the hot water in a household is produced electrically, the annual consumption may be said to vary between 1,500 and 3,500 units.

Electric Washing Apparatus

There are few domestic applications of electricity which are so effectively labour-saving as those connected with washing, which usually constitutes a very considerable part of the weekly work in the house. Apparatus for this purpose has the additional advantage of small consumption of electricity, and, while certain appliances are not cheap in capital cost, some of these may be hired from supply companies for a small quarterly charge, while many may be obtained by hire-purchase. Even the expensive apparatus can be shown to save its initial cost in laundry bills in a short time.

Washing appliances may be divided into :

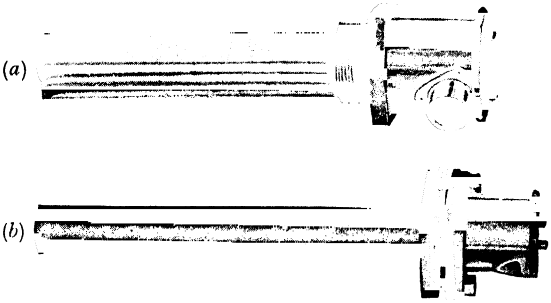
(*a*) Washing machines.
(*b*) Wash boilers.
(*c*) Irons.

(*a*) Washing machines have a capacity of 8 or 10 gallons, and enable a tubful of clothes to be washed in from 3 to 8 minutes. They are fitted with a small electric motor (usually ¼ horse-power, using about 250 watts) which is used for driving an impeller, which carries out the equivalent of dollying the clothes, and a wringer, mounted above the container. They may also be fitted with an ironer, driven by the same motor, which can be fitted in place of the wringer quite simply when required. The heating element of the ironer has usually 1,000 or 1,200 watts loading.

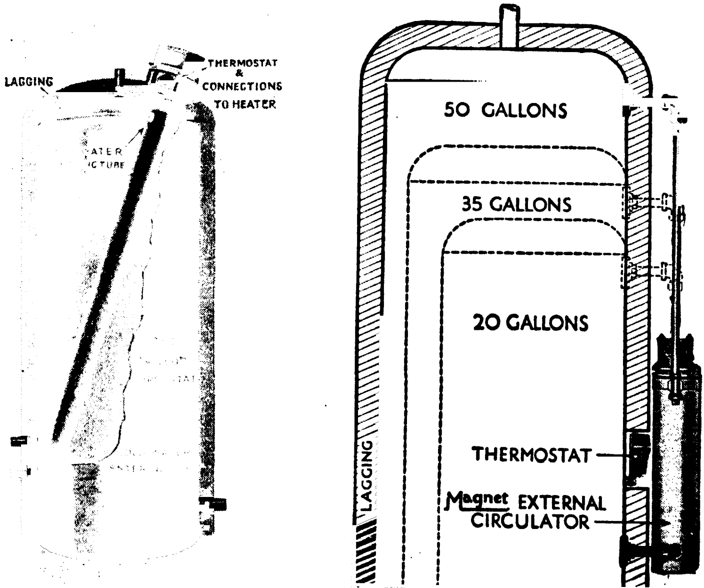
The electricity consumption for a complete wash in the case of a medium-size household is only about ¼ to ½ unit, so that the cost, per wash, is not likely to exceed 1*d.*, even if electricity is expensive. The cost of these machines varies from about £16 to £35, with an extra cost of about £10 for the ironer.

(*b*) Wash boilers are for the purpose of boiling the water containing the clothes as distinct from carrying out the dollying and wringing operations. They contain a 2-, 3- or 4-kilowatt heater, are commonly of 8 or 10 gallons capacity, and are often designed so that circulation of the water is brought about to remove the dirt from the clothes more effectively. A switch for 3-heat control is often fitted. The cost of these boilers usually lies between £3 and £6, and, in some districts, they may be hired from the supply authority for a few shillings per quarter.

In some types a hand-operated wringer is supplied as an extra. Again, some of the washing machines mentioned under (*a*) are fitted with a heater which may be of a few hundred watts loading —to keep the washing water hot after adding it to the clothes—



By courtesy of Heatrae, Ltd.



(*c*) *By courtesy of Santon, Ltd.*

(*d*) *By courtesy of General Electric Co., Ltd.*

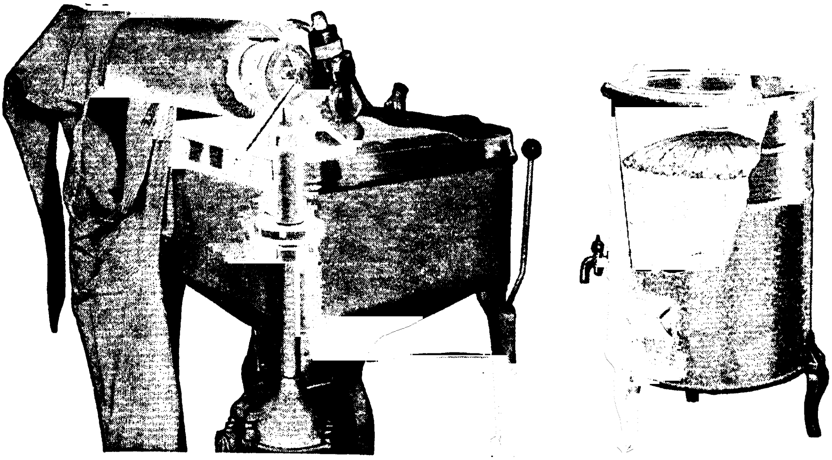
FIG. 27.—CONSTRUCTION OF IMMERSION HEATERS AND CIRCULATORS.

or may be 3 or 4 kilowatts—sufficient actually to boil the washing water from cold.

(*c*) A large variety of electric irons, ranging in price from about

5*s*. to 30*s*., is available. These may be obtained in weights of from 3 lb. to 8 lb., and with loadings of 250 to 500 watts. Most makes have a heel rest to avoid the necessity for a stand, and have also a thumb rest, while some models have a groove along the sides of the sole plate to facilitate ironing under buttons.

Whilst most electric irons are heated by connection to the supply through a length of flexible cable, a few models are available which may be heated by placing them on a special panel or stand which has a plunger-operated switch. The flexible cable is then unnecessary, the iron having a considerable heat capacity.



By courtesy of Hotpoint Electric Appliance Co., Ltd. *By courtesy of General Electric Co., Ltd.*

FIG. 28.—WASHING MACHINE AND WASH BOILER.

Fig. 28 shows the construction of a washing machine with a rotary ironer fitted to replace the usual wringer, and also that of a wash boiler which has a central tube carrying up the hot soapy water, which then sprays over the clothes.

Other Domestic Applications

Two applications of electricity in the home which have not already been mentioned are the vacuum-cleaner and wireless set. Of both of these there are models far too numerous to mention. The former has a small electric motor which takes from 150 to 250 watts. In the case of wireless sets, batteries may be dispensed with, and, when operated from the electric mains, the consumption is very small—of the order of 25 watts or even less.

Summary

The following table gives a summary of the consumption and costs of most of the more important domestic appliances :

TABLE XX

Apparatus.	Approximate capital cost.	Approximate quarterly hire charge (if hired).	Wattage.	Domestic energy consumption (units (kWh) of electricity).	Hours of use for a consumption of 1 unit.
	£ s. d.				
Lamps	0 1 9	—	5–500	2–8 per wk.	2–200
Cooker (full size)	12 0 0	4*s.*–10*s.*	5,000–8,000	1 per day per person	$\frac{1}{8}$–$\frac{1}{5}$ (with heat full on)
Cooker (breakfast)	2 0 0	—	750–3,500	—	$\frac{1}{3}$–$1\frac{1}{3}$
Kettle	1 0 0	1*s.*	500–2,000	—	$\frac{1}{4}$–2
Boiling Ring	1 10 0	—	500–2,000	—	$\frac{1}{2}$–2
Warming Plate	1 10 0	—	100–500	—	2–10
Saucepan	1 10 0	—	250–500	—	2–4
Toaster	1 0 0	—	500	—	2
Coffee Percolator	1 10 0	—	300–500	—	2–3
Refrigerator	20 0 0	—	150–300	1 per day	$3\frac{1}{3}$–$6\frac{2}{3}$ when running continuously
Dish Washer	30 0 0	—	200–300	—	3–5
Fire	5*s.*–£10	2*s.* 6*d.*	500–5,000	—	$\frac{1}{5}$–2
Tubular Heater	5*s.* per ft.	—	60–200 per ft.	1,000 per ann. per kW installed	5–$16\frac{2}{3}$ when full on continuously
Towel-rail	2 0 0	—	50–500	—	2–20
Hair Dryer	1 0 0	—	600	—	$1\frac{2}{3}$
Fan	1 10 0	—	20–100	—	10–50
Water Heaters :					
(*a*) Geyser type	5 10 0	—	5,000–12,000	$\frac{1}{3}$ per gal. 1,000–3,500 per ann.	$\frac{1}{12}$–$\frac{1}{6}$
(*b*) Storage type	£5–£50, depending on size and type	5*s.*–10*s.*	500–3,000		$\frac{1}{3}$–2 when full on continuously
(*c*) Immersion	5 0 0	2*s.* 6*d.*–4*s.* 6*d.*	1,000–4,000		$\frac{1}{4}$–1 when full on continuously
Washing Machine	£25 (£35 with ironer)	—	250 without water heating or ironer	$\frac{1}{2}$ per wk.	4
Wash Boiler	4 10 0	3*s.*–5*s.*	2,000–4,000	—	$\frac{1}{4}$–$\frac{1}{2}$ when full on
Iron	5*s.*–£1 10*s.*	1*s.*	250–500	50–100 per ann.	2–4
Vacuum-cleaner	£3–£20	—	150–250	50–100 per ann.	4–$6\frac{2}{3}$

The difficulties of preparing such a table are obvious when one considers the rapid development of domestic electrical appliances and their varying (usually falling) price. Nevertheless, it was felt to be desirable to summarize in this way, so that the reader may have some guide as to the costs and consumption involved with different appliances. The quarterly hire charges given are only for equipment which is most commonly hired. Supply authorities vary considerably in the number of appliances hired, but the charges given in the table are representative.

As regards the figures in the last column, these apply rigidly in most cases, but when apparatus is thermostatically controlled, as in the case of thermal storage-water heaters, refrigerators, and tubular heaters, the hours of use per unit consumption will usually be much greater than those stated, since they are in full operation only intermittently. An attempt has been made, in the fifth column, to give general figures for annual or weekly consumption.

If possible, it is perhaps advisable to hire rather than to purchase, because maintenance is usually included in the hire charge. Where appliances are costly, and cannot be hired, hire-purchase facilities with low monthly rates are frequently offered either by the supply authority or by the manufacturer's agents, some degree of maintenance often being undertaken.

To give some idea as to the size of the quarterly account for a domestic consumer having a fairly extensive electrical equipment, let us consider a house having the following: electric light, cooker, fire, kettle, thermal storage-water heater, washing machine, vacuum-cleaner, iron, and some small miscellaneous appliances. The quarterly account, with a two-part tariff consisting of a fixed charge, together with a unit charge of ¾*d.*; assuming moderately full use of the equipment, might be somewhat as under:

QUARTERLY ACCOUNT

	£	*s.*	*d.*
Fixed quarterly charge	0	18	0
Light (64 units at ¾*d.*)	0	4	0
Fire (500 units at ¾*d.*)	1	11	3
Cooker (270 units at ¾*d.*)	0	17	0
Hire of cooker	0	8	0
Kettle (90 units at ¾*d.*)	0	5	8
Hire of kettle	0	1	0
Water heater (400 units at ¾*d.*)	1	5	0
Hire of water heater	0	7	0
Iron, vacuum-cleaner, washing machine, and miscellaneous (50 units at ¾*d.*)	0	3	1
Total units, 1,374. Total	£6	0	0

Average charge per unit (including hire of appliances) = $1\frac{1}{20}$*d.*

Considering the service given, this charge cannot be considered excessive.

CHAPTER VIII

APPLICATIONS OF ELECTRICITY IN AND AROUND FARM BUILDINGS

THAT the use of electricity for domestic purposes is both highly convenient and economically sound has been shown in the previous chapter. For a large number of purposes in and around the farm buildings it is equally convenient and almost equally sound economically, provided the price of electricity is not too high. Since, however, much greater publicity has naturally been given to domestic appliances than to farm applications, the latter are not yet fully appreciated. With the rapid extension of rural electrification, it must only be a matter of time before most of the operations carried out in the farm buildings are electrified. Considerable progress has already been made in connection with several of these operations, and a review of these will be given below.

Classification of Electrified Processes

We may classify the various branches of farm work to which electricity has been applied as under :

(1) Operations utilizing barn machinery.
(2) Pumping.
(3) Dairy work.
(4) Poultry farming.
(5) Crop treatment

Although fitting in no special one of these classes, electric lighting in the buildings is, of course, in very general use on farms having an electricity supply. It is, perhaps, the most obvious, and at the same time the most generally beneficial, application of electricity outside the farm-house, and can be strongly advocated from the points of view both of convenience and economy. In winter time a considerable amount of work has to be done in and around the buildings after dark, and although in the past this has been carried out by oil lamps, no one can say that such lighting is efficient, and the improvement resulting from the use of even low-wattage electric lamps in the buildings is truly remarkable. Except that the method of wiring to be adopted in farm buildings must receive special attention on account of the much rougher treatment which it is bound to receive in such situations as compared with house wiring, there are no special difficulties in such lighting. Most of the statements already made regarding lighting costs still apply, although the cost of installation will be somewhat higher than that in the house because of the longer runs of cable which will probably be required, and also because of the heavier fittings necessary to give satisfactory service under more arduous conditions. The method of wiring is more the concern of the electrical contractor or supply engineer than of the consumer, but the latter should be careful to guard against false economy in reducing the number of lighting points and in allowing a cheap but badly planned installation to be carried out. There is a temptation to install poor-quality material simply because it is in rough buildings, but it must be stressed that this is most unwise, since such situations demand better-quality material than that in the house rather than worse, if satisfactory service is to be obtained.

1. Barn Machinery

Among barn machines which may be electrically driven are those for the following purposes, the approximate output per unit of electricity consumed and the horse-power required being given in each case :

TABLE XXI

Operation.	Output per unit of electricity consumed.	Horse-power required.
Cake breaking	1–1¼ tons	½–3
Chaff cutting	4–8 cwt.	2–5
Root cutting and pulping	2–3 tons	½–2
Crushing	6–8 bushels	3–8
Grinding	2–3 bushels	3–8
Kibbling	6–8 bushels	3–8
Threshing 42-in. drum 54-in. drum	4–7 bushels	12–15 (baling press requires 2–3 h.p. additional)
Sawing	—	2–8
Mixing	½–1 ton	2–4
Bale or sack hoisting	—	2–5
Elevating	About 2 tons, depending upon height raised	3–5
Grindstone	4–8 hours' use	¼

It will be observed from the above table that most of the operations require not more than 5 h.p. The speeds required vary from about 50 to 1,500 revolutions per minute. A list of suitable speeds for various processes is given below, although the exact speed to be used is not critical in most cases, and a single motor with some form of gearing to give a range of 4 or 5 different speeds can be employed satisfactorily.

TABLE XXII

SUITABLE SPEEDS FOR VARIOUS PROCESSES

Process.	Speed (revolutions per minute).
Cake breaking	80–200
Chaff cutting	150–300
Root cutting	80–200
Crushing	500
Grinding	500–1,800
Threshing	1,000–1,200
Ensilage cutting	300
Hoisting	80–300
Circular saw.	1,000–1,500

For machines which may otherwise be turned by hand, speeds up to 200 r.p.m. are generally suitable.

Choice of Motor and Method of Drive

Electricity supply in rural districts is now almost entirely alternating current, and future extensions will certainly be so. In general, therefore, alternating-current motors must be used, only fractional horse-power motors suited to both alternating and direct-current supply being obtainable. Now, A.C. transmission and distribution is usually carried out by means of what is called a " three-phase " supply, which is practically equivalent to three different circuits being carried on the same set of poles. For lighting and small power uses, only one of these circuits is brought to the consumer's premises, and his supply is then said to be " single-phase."

For the larger power uses, however, a three-phase supply is necessary, all three wires from the distribution system being brought to the consumer's premises. Three-phase wiring is, of course, rather more expensive than single-phase, but three-phase motors have more satisfactory characteristics than single-phase, which are only manufactured in fairly small sizes.

One may summarize the matter by saying that for sizes under 1 h.p. single-phase motors may be used, but for larger sizes three-phase motors are usually necessary. The most satisfactory type of 3-phase motor for farm use is the squirrel-cage motor, which is very robust, simply constructed, with very low maintenance cost, and which may be subjected to rough or unskilled usage without damage. Owing to the large starting current—from twice to five or six times full-load current—taken by this type of motor, it may be necessary to use a three-phase slip-ring induction motor for powers above about 7½ h.p. in order to fulfil the requirements of electricity supply authorities concerning such starting currents. Several manufacturers have placed on the market motors specially designed for farm use. The windings are vacuum impregnated and are protected against the action of dust, moisture, uric acid, and ammonia fumes. Incidentally this construction prevents the entry of vermin—an important consideration when the motor is used in farm buildings. Such motors should be sufficiently enclosed for them to be protected from rain or splashing when used outdoors. With the standard form of protection there is ample ventilation, so that the heat produced within the motor can be dissipated satisfactorily. Totally enclosed motors should not be used unless absolutely necessary because of (say) a very dusty situation, since then a larger and more expensive motor is required in order that the cooling may be adequate.

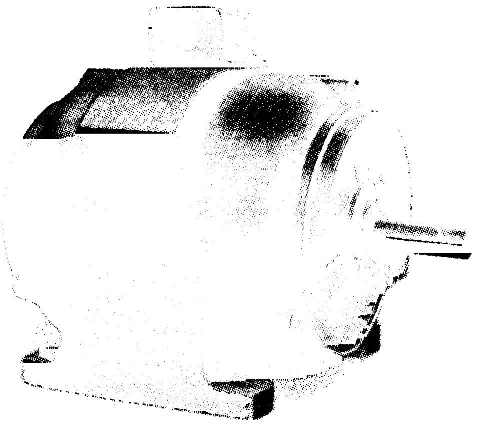


FIG. 29.—DRIP-PROOF SQUIRREL-CAGE INDUCTION MOTOR FOR FARM USE.

By courtesy of Metropolitan-Vickers Electrical Co., Ltd.

The motor should be capable of being run either vertically or horizontally, and should have ball or roller bearings with grease lubrication and protection from dust. The starter should always be fitted with overload and no-volt protective devices to prevent damage if the motor is overloaded or in the event of failure of the supply. A 5-h.p. squirrel-cage motor for farm use is shown in Fig. 29.

In addition to robust construction and low maintenance cost as compared with other driving machines, electric motors have the advantages that they can be mounted in almost any position, including the ceiling, they occupy a smaller space than any other form of drive of the same horse-power, and, of course, require no fuel storage or water supply.

With regard to the method of drive, the choice lies between :

(*a*) A line shaft with belt drive for the various barn machines.

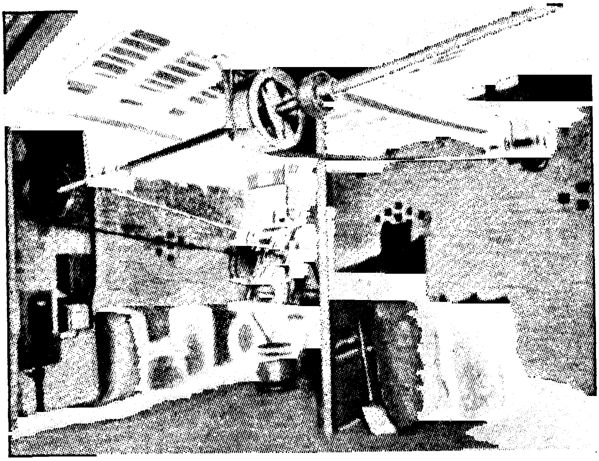
(*b*) Individual drive, i.e. a separate motor permanently set up for the drive of each machine.

(*c*) Portable motors with gearing, the drive being through a belt or other flexible coupling. The relative advantages and disadvantages of these three methods are as follows :

(*a*) In cases where a line shaft already exists for a drive by a steam or other engine, the simplest method of conversion is, of course, to utilize this shafting, replacing the engine by an electric motor. An advantage of this method is that there is only one motor to be installed and maintained, so that little time is wasted in setting up machinery for running. The horse-power of the motor used depends upon what machines are likely to be in use at the same time. Generally speaking, a 7½- or 10-h.p. motor will be sufficient. It is a simple method of driving, but necessitates keeping a number of belts in order. Again, unless efficiently maintained, as much as 1 or 2 h.p., depending upon the length and number of bearings, may be absorbed in driving the line shaft alone, thus involving considerable waste of power. The fact that many farm buildings are old and in various stages of disrepair increases the difficulty of obtaining a satisfactory line-shaft drive. Before installing a motor, realignment of the shafting and new bushings to the bearings may be advisable. Ball bearings are fitted in more modern drives of this type.

Unless the barn machines have already been installed with this method of drive in view, it is probable that they will be scattered in different buildings, in which case line shafting could not be used without considerable rearrangement. Fig. 30 gives two examples of electric drive through line shafting. In one case the motor is mounted overhead on joists, and in the other the motor is pipe-ventilated, since it is driving a grinding mill in a very dusty atmosphere. In this case the pipe-ventilated motor is alternative to the totally enclosed motor.

(*b*) Individual drive is ideal as regards the saving of time in setting up machinery for running, but is expensive in first cost. Again, although maintenance of such motors is low, it is impossible to neglect the fact that there is an increased possibility of trouble with such multiplication. Also, with a motor perman-



By courtesy of Metropolitan-Vickers Electrical Co., Ltd.

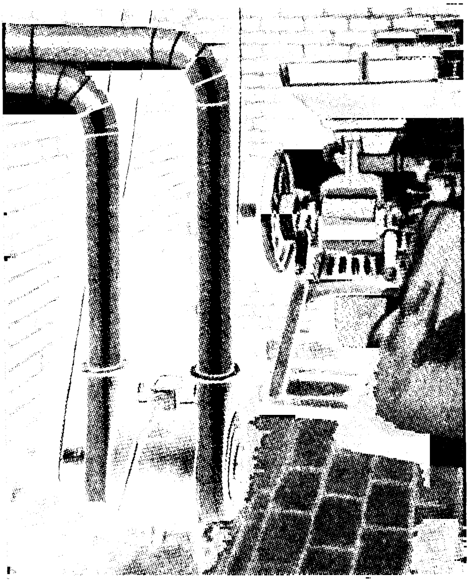


FIG. 30.—ELECTRIC DRIVES THROUGH LINE SHAFTING.

By courtesy of British Thomson-Houston Co., Ltd.

ently set up for individual drive, there is likely to be more difficulty in arranging an alternative drive in the event of failure. On the other hand, the time saved in setting up (say) a portable motor may outweigh other considerations, and as each motor will be used intermittently, the life will be longer than with a portable multi-purpose motor.

This method of drive is perhaps more particularly justifiable in the case of machines requiring a large amount of power, such as a grinder or thresher. The motor may be direct-coupled and built into the machine, or may drive through a belt as in Fig. 31, in which a motor-driven chaff cutter is shown.

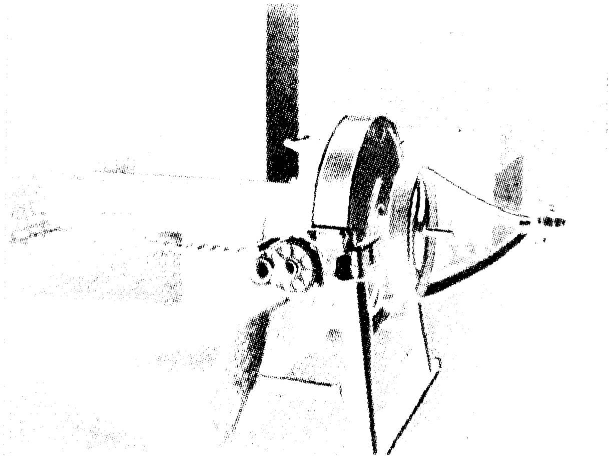


FIG. 31.—BELT-DRIVEN CHAFF CUTTER.
By courtesy of Metropolitan-Vickers Electrical Co., Ltd.

(*c*) The portable motor drive has the advantage that only one motor is required for a number of different machines, thus saving initial costs and enabling experience to be gained with electric drive, so that an opinion may be formed as to the advisability of individual drive for certain machines at a later date. This method is to be recommended for the farmer when starting to use electric power.

Such motors are obtainable in sizes up to 10 or 15 h.p., above which size the weight becomes too great to be handled easily. Partly for this reason, sizes up to about 5 h.p. are commoner than the larger sizes, and these are sufficiently large for most purposes.

Various forms of portable motor are available, some of these being illustrated in Figs. 32–35. Most of these have a starter and some form of circuit breaker, either carried on the frame or on the truck upon which they are mounted. The truck, which may, of course, be made on the farm if desired instead of being purchased with the motor, should have two wheels—fairly wide for easy transport—for motors up to about 7½ h.p., four wheels being advisable for more powerful motors. Both motor and starter are enclosed, so as to be weather-proof, and suitable for operation by unskilled labour. They are supplied with a long length (40 feet or more) of tough flexible cable, which should contain an earth core as a safeguard against shock, all exposed metal parts of the equipment being earthed. The method of drive is by belt or by a cardan shaft, which may be used in conjunction with gearing to give a large range of speeds from about 40 r.p.m. upwards. Either by means

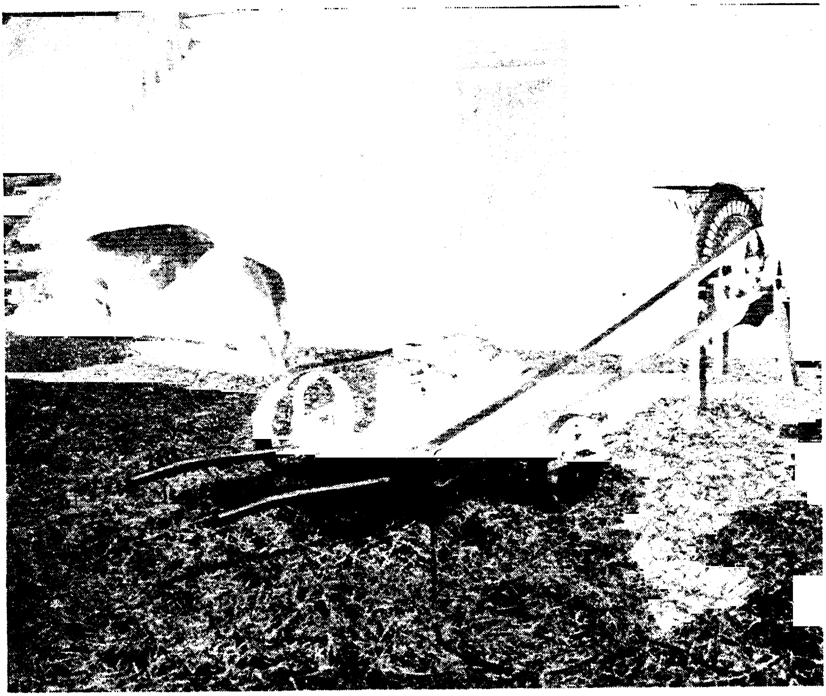


FIG. 32.—ROOT SLICER DRIVEN BY A PORTABLE MOTOR THROUGH A COUNTER-SHAFT.

By courtesy of Fuller Electrical and Manufacturing Co., Ltd.

of such a shaft or by the inclusion of a range of pulleys of different diameters with a pulley drawer to facilitate changing, the time required for setting up the motor for a drive is reduced as much as possible.

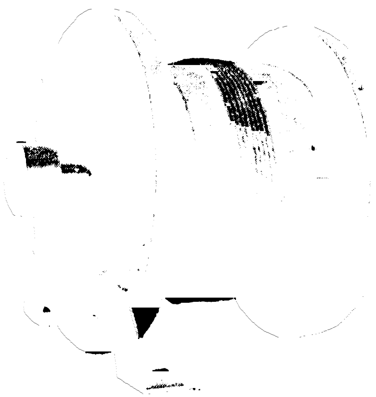


Fig. 33.—G.E.C. 5-H.P. "Drumotor."
By courtesy of the General Electric Co., Ltd.

The starting process is very simple, consisting merely of the pressing of a button or the closing of a switch, or, at most, the throwing over of a switch through two positions.

Fig. 32 shows a portable motor driving a root slicer at a slow speed through a countershaft carried on the truck of the motor, while Fig. 33 shows the G.E.C. 5-h.p. "Drumotor," in which the control gear is contained within the drum itself. The motor is transported by rolling on the rims, the hinged foot for use when the motor is driving being moved upwards to clear the rim for this purpose. The cable is wound round the drum when not in use, and the plug connector is housed in a recess in the drum.

In Figs. 34 and 35 are shown a 5-h.p. squirrel-cage, drip-proof motor mounted, with its starter, on timber skids instead of a truck, and a ½-h.p. dual-speed barrow motor for driving machines which would otherwise be turned by hand. This motor is geared, and has fast and slow grooved pulleys driving through a "V" belt.

Motor Speeds and Speed Reduction

Without gearing, the motor speed may be from 600 to 2,800 r.p.m., and, as already seen, this is too high for many purposes. Portable motors often run at 960 or 1,000 r.p.m. and line shafting at speeds up to 300 or 400 r.p.m., the motor for the drive of line shafting often running at 960 r.p.m. For direct coupling the motor speed may be 500 to 750 r.p.m.

When pulleys are used for speed reduction, the maximum reduction ratio for efficient working is about 4 to 1, with ordinary flat belts, although higher ratios are obtainable with special belts or "V" ropes.

The required sizes of pulleys may be calculated from the fact that the speed obtained is in the inverse ratio of the pulley diameters. Thus, for example, a motor running at 1,200 r.p.m. and having a 6-inch pulley would drive a machine having an 18-inch pulley at 400 r.p.m., the ratio of the pulley diameters being 3 to 1.

Initial and Working Costs of Motors

It is difficult to give exact initial costs of the different methods of drive, since these depend upon the amount of auxiliary equipment required in the form of belts, pulleys, etc., but the motor costs are of the following order :

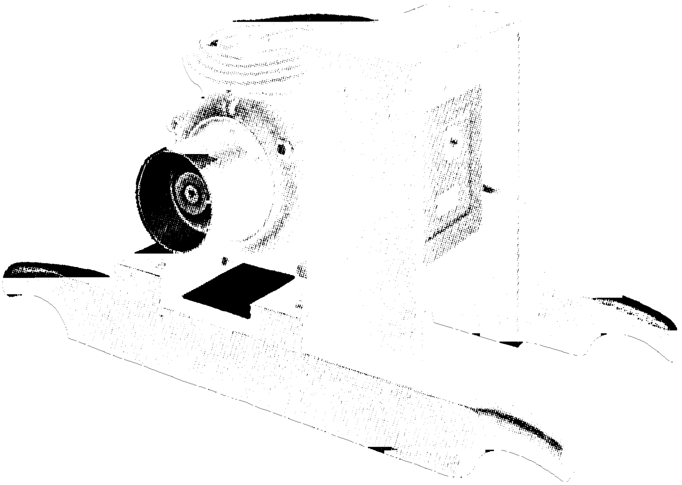


FIG. 34.—MOTOR AND STARTER MOUNTED ON SKIDS.

By courtesy of the General Electric Co., Ltd.

Single-phase motor, ⅛–1 h.p.	£3 to £6. according to size.
3-phase squirrel-cage motor (standard protected type) :	
1–5 h.p..	£5 to £12
5–10 h.p.	£12 to £25

The price of totally enclosed squirrel-cage motors is from 50 to 100 per cent. higher than for the standard protected type, while protected slip-ring motors are about twice as expensive as the squirrel-cage type. For most purposes, however, the prices quoted above may be taken as representative.

Portable motors, with truck where required	from £18 for 3 h.p. upwards for larger sizes.
" Drumotor," 5 h.p., 3-phase	£37 10*s*.
Dual-speed (½-h.p.) barrow motor with accessories	£20 15*s*.

Most of these motors require a starter, and the cost of this, when not already included in the price of the motor, will be of the order of £2 or £3. The price of pulleys is from about 8*s*. to £1 each.

The running costs depend, of course, upon the load on the motor. Thus, when running on no load, the motor may take up to about 10 per cent. of the power required at full load. As already pointed out when dealing with power consumption of motors, a rough rule is to allow 1 kilowatt input per horse-power of rated output, although this will give an input on the high side in most cases unless the motor is very small.

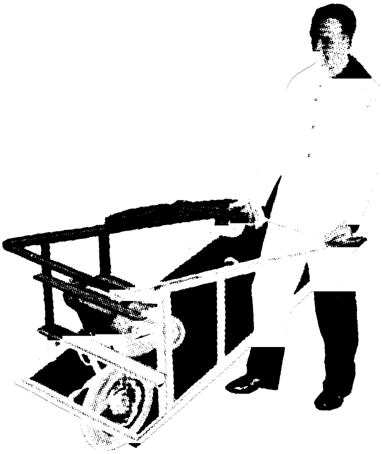


FIG. 35.—½-H.P. DUAL-SPEED BARROW MOTOR.

By courtesy of the General Electric Co., Ltd.

In most applications to the drive of barn machinery the horse-power demanded from the motor will be extremely variable. Thus, for example, in grinding or crushing, the power required will depend upon the rate at which the grain is fed in and upon the degree of fineness of the grinding, so that the figures given in the table on p. 142 can be regarded only as reasonable averages for the processes mentioned. In any event, since the starters of these motors are fitted with overload protective devices to stop the motor if appreciably overloaded, the maximum consumption cannot be much greater than the energy equivalent of full load. Thus, for a 5-h.p. motor, the energy consumption per hour cannot be much greater than 5 units, although in all probability it will be considerably less than this.

Competitive Forms of Drive

The competitive forms of power plant for the drive of farm machinery are :

(*a*) Gas engines (in a few cases).
(*b*) Heavy oil engines.
(*c*) Petrol or paraffin engines.

Small engines of these types have been used for small-power purposes with a reasonable degree of satisfaction, and have undoubtedly served a very useful purpose, their low fuel costs, in some cases, being in their favour. The following brief review of these engines may be useful before discussing relative annual costs:

(*a*) *Gas Engines.*—These are not very important to the rural industrialist, since gas is usually available only in the immediate vicinity of the towns. Gas engines having outputs of as low as ¼ h.p. are available, but the smaller engines are not economical, and sizes under 3 or 4 h.p. are scarcely to be recommended for rural work.

(*b*) *Diesel Engines.*—These use heavy or so-called " crude " oil, which is cheaper than paraffin, although the advantage in price is now much less marked than formerly, owing to the tax upon heavy oils. High compression is used, and these engines are consequently heavy (about 1½ cwt. per horse-power) and somewhat expensive in first cost (from about £55 for a 5-h.p. engine upwards, according to size), their main advantage being their economy in fuel provided the cooling and lubrication are adequate and the quality of the fuel is suitable. They need skilled attention, and the maintenance charges are thus apt to be heavier than for (say) paraffin engines, while starting is usually neither a rapid nor very simple operation. Diesel engines are not commonly made in small sizes, and speaking generally they are not suited to farm use.

Semi-Diesel Engines.—These engines also use heavy oil, although the quality of the oil is perhaps not quite so critical as with Diesels. They are of simpler construction than the latter, and can be obtained in fairly small sizes. Like Diesels they require periodical adjustment and repairs, and are not so suitable for use in rural work as paraffin engines.

(*c*) *Paraffin and Petrol Engines.*—These have been largely used in the past for farm and other rural work. Paraffin engines have lower fuel costs than petrol engines, although the latter require less cleaning and decarbonizing. Paraffin engines are started on a small quantity of petrol, and change over to paraffin after a few minutes, when the cylinder and induction pipe have warmed up. Their low fuel cost is their greatest advantage. Petrol engines must be run at high speeds for satisfactory results. The capital costs of these engines are about £20 for a 2-h.p. engine and from £40 to £80 for sizes ranging from 5 to 10 h.p.

Comparison between Electric Motors and Engine Drives

Since running costs must always be an important factor, these will be dealt with first. The annual costs connected with any method of drive may be classified as :

(*a*) Interest charges on the capital outlay.
(*b*) Insurance of the plant.
(*c*) Depreciation charges.
(*d*) Maintenance charges.
(*e*) Fuel and lubrication costs.

Very frequently, in comparing alternative methods of drive, the fuel costs alone are considered, or, at least, are given undue weight. A comparison on the basis of fuel costs alone is, however, worthless. With a large number of hours of use per annum high interest, depreciation, and maintenance charges may become less important, but for a small number of hours of use, on the other hand, the so-called fixed charges, or "overheads," completely outweigh the advantage of a low fuel charge. It is essential, therefore, to take these charges into account if a true estimate of the total annual costs is to be obtained. Of the five classes of costs listed above the first two are fixed, for a given machine, and are directly proportional to the capital cost of the plant. Interest charges may be taken as 4 per cent. of the total capital cost, including the cost of erection on the site, and insurance may be taken as 2 per cent. of the capital cost of the engine.

Depreciation and maintenance costs, while dependent upon the capital cost, are not quite constant, but depend also upon the annual number of hours of use. An engine in use for only a small number of hours per annum will last longer (i.e. there will be less depreciation) and will cost less to maintain in working order than one which is used for longer periods. Fuel and lubrication costs will, for a given load, be proportional to the number of hours of use.

Since capital costs affect four of these five annual costs, we may attempt to compare these for different types of drive. Expressed as a ratio, taking the cost of an electric motor as unity, we have:

	Capital cost as a ratio.
Electric motor (squirrel-cage with standard protection)	1
Petrol-paraffin engine	2½–3¼
Gas engine	2¾–3½
Heavy-oil engine	4

Thus interest and insurance charges for electric motors (squirrel-cage type) are only ¼ to ⅖ of those for the various types of engines. Their life (at least twenty years) is roughly double that of these engines, so that depreciation charges will be only ⅛ to ⅕ as much, while maintenance charges are so very small as to be almost negligible.

The fuel consumptions of the various types of drive (excluding lubrication) are approximately as under:

	Consumption per horse-power-hour of output.
Gas engine	25 cubic feet of gas
Heavy-oil engine	½ pint of fuel oil
Paraffin engine	¾ pint of paraffin
Petrol engine	½ pint of petrol
Electric motor	$\frac{9}{10}$ unit of electricity

The prices of the various fuels vary in different districts and also with the amounts purchased. The present price of heavy oil, for example, is about 5½*d.* to 6½*d.* per gallon if bought in 500-gallon quantities but may be 8*d.* or more per gallon if bought in 40-gallon or smaller drums. In view of the cost of storing large quantities of oil, it is doubtful whether the small user would obtain his fuel at the lower price. Electricity charges, however, certainly vary in different districts more than do the prices of oil. For power purposes the charge may vary from ½*d.* to 2*d.* per unit.

As an example of the way in which the cost per horse-power-hour of output is influenced by the fixed charges and by the number of hours of use per annum, consider the following:

Example.—A 10-h.p. heavy-oil engine costs £100 or, with erection costs, £120, while a 10-h.p. squirrel-cage motor costs £20, or, with wiring, £25. Cost of electricity, 1½*d.* per unit. Cost of fuel oil, 8*d.* per gallon. Cost of lubricating oil for engine, 3*s.* per gallon.

Assume both to be on full load throughout their use. Then with a use of 20 hours per week (say 1,000 hours per annum), we have:

For Engine	£	*s.*	*d.*
Interest charges (at 4 per cent.)	4	16	0
Insurance (2 per cent. of cost of engine)	2	0	0
Depreciation (life 10 years)	12	0	0
Maintenance (5 per cent. of cost of engine)	5	0	0
Lubricating oil	1	0	0
Fuel oil (at ½ pint per h.p.-hour)	20	16	0
Total	£45	12	0
Total h.p.-hours of output	10,000		
Cost per h.p.-hour of output	$1\frac{1}{10}$*d.*		

For Motor	£	*s.*	*d.*
Interest charges (at 4 per cent.)	1	0	0
Insurance (2 per cent. of cost of motor)	0	8	0
Depreciation (life 20 years)	1	5	0
Maintenance (including lubrication)	0	10	0
Electricity (at $\frac{9}{10}$ unit per h.p.-hour)	56	6	0
Total	£59	9	0
Total h.p.-hours of output	10,000		
Cost per h.p.-hour of output	$1\frac{4}{10}$*d.*		

If, instead, the use is only 1 hour a day (say 350 hours per annum), we have :

For Engine	£	*s.*	*d.*
Interest	4	16	0
Insurance	2	0	0
Depreciation (life 12 years)	10	0	0
Maintenance (reduced with reduced use)	2	0	0
Lubricating oil	0	8	0
Fuel oil	7	6	0
Total	26	10	0
Total h.p.-hours of output	3,500		
Cost per h.p.-hour of output	$1\frac{8}{10}$*d.*		

For Motor	£	*s.*	*d.*
Interest	1	0	0
Insurance	0	8	0
Depreciation (life 25 years)	1	0	0
Maintenance	0	5	0
Electricity	19	14	0
Total	£22	7	0
Total h.p.-hours of output	3,500		
Cost per h.p.-hour of output	1½*d.*		

This example shows the effect of the high fixed charges in the case of the engine in increasing the cost per h.p.-hour when the number of hours of use per annum is small—as it may well be in the case of a fairly small farm or workshop.

It will be seen that the cost per h.p.-hour in the case of the motor is very little different from the price per unit of electricity. If, therefore, the price of electricity is 1*d.* per unit, the cost per h.p.-hour in the motor case becomes 1*d.* (or slightly less in the case of 1,000 hours' use). The cost per h.p.-hour for the engine when used 8 to 10 hours per day, taking the cost of fuel under these conditions at 6*d.* per gallon, is about ⅝*d.* On the other hand, if the electric motor were to be used to this extent, it is probable that a reduced charge for electricity would be obtainable from the electricity supply company.

Advantages of Electric Motors

In the above estimate of costs only those which can be estimated with reasonable accuracy have been taken into account in arriving at figures for the maintenance and depreciation of engines. Other factors which are difficult to assess in terms of actual costs must nevertheless be taken into account if a fair comparison between electric motors and oil and other engines is to be made. Thus, for example, the maintenance and depreciation costs taken above are based on the assumption that the engine concerned is in the hands of a person with a certain amount of skill in maintaining the machine, and who is capable of carrying out minor adjustments, the cost of which is not, therefore, taken into account. The maintenance costs given represent those for necessary replacements of worn parts together with some periodical attention from a skilled mechanic. If outside assistance has to be obtained for even minor adjustments the costs given will have to be increased considerably.

Again, no account is taken of the time wasted in starting the engine, although this may be considerable in cold weather, or of any loss of production due to time taken in the necessary periodical overhauls of the motor.

The whole question may be summarized by listing the advantages of electric motors as under :

(i) Simplicity of starting and of operation, no skilled attention being necessary.

(ii) Small number of parts—only one moving part—and very robust construction.

(iii) Low initial and maintenance costs.

(iv) Low depreciation (life usually at least twenty years).

(v) Reliability.

(vi) Small space per horse-power of output and the possibility of mounting fixed motors in almost any position.

(vii) Cleanliness and absence of fumes.

(viii) Absence of fuel storage or water supply requirements.

(ix) Even turning, which gives increased life to the machine being driven.

(x) Considerable overload capacity, and only a small reduction of efficiency as the load is reduced, so that the power used is proportional to the work to be done.

(xi) Low weight per horse-power, giving increased portability.

It will be appreciated that these advantages are so important that they cannot be put on one side lightly, even if it is shown that, at the price charged for electricity in a particular district, a certain type of engine would give rather lower running costs. In brief, the service given must be weighed as well as the actual comparative costs.

Rothamsted Experiments

Some very valuable experiments upon the relative costs of driving certain farm machines by electricity and by oil engines have been carried out at Rothamsted Experimental Station, Harpenden, during the last two or three years, and the results have now been published.[1]

The following is a brief summary of these results :

Threshing Experiments.

Driving Machines used :

(i) 20-h.p. portable electric motor.
(ii) New 10–20-h.p. tractor.
(iii) Old 10–20-h.p. tractor.

Fuel costs :

Electricity, 1·42*d.* per unit.

(The electricity tariff was a two-part one, the unit charge being 1*d.* The additional 0·42*d.* represents the fixed quarterly charge spread over the number of units used per quarter. This method of arriving at the price per unit is used throughout the estimations of costs.)

Paraffin, 6*d.* per gallon.

Petrol (for starting paraffin engine), 1*s.* 2½*d.* per gallon.

Lubricating oil, 1·9*d.* per hour.

Life and maintenance of machines (estimated) :

Motor—Life, 20 years ; annual maintenance, 2 per cent. of original cost.

Circuit—Life, 25 years ; annual maintenance, 2½ per cent. of original cost.

Tractor—Annual maintenance, 3¾ per cent. of original cost.

Depreciation allowed in calculating costs 22½ per cent. for tractors and 7½ per cent. for electric motors (these being the depreciation allowances made for income-tax purposes).

Interest charge at 5 per cent. of the value of the plant at the beginning of the year. In all the tests the output of grain was 2 tons per hour, and both the motor and tractor were on about half-load, the mean power consumption of the motor being 8 kW and the fuel consumption rate for the tractor 1·36 gal. per hour. The threshing machine had a 48-inch drum.

The comparative costs for the same operation were found to be :

Electric Motor and Equipment :	*d.*
Electricity cost	11·4
Overheads	4·8
Total	16·2

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[1] *The Use of Electricity in Agriculture,* published by Rothamsted Experimental Station. The author is indebted to Sir E. J. Russell, D.Sc., F.R.S., Director of the Rothamsted Experimental Station, for permission to reproduce the above information and for his kindness in affording the opportunity of inspecting the work being carried out.

Tractor:

	d.
Fuel and lubricating oil cost	10·1
Overheads	9·4
Total	19·5

These tests indicate, therefore, that, including overhead expenses, electric drive is cheaper at anything less than 1·85*d.* per unit.

Grinding Experiments

It is pointed out that in this case the comparison was not so straightforward as in the threshing experiments, owing to the number of variable factors in the use of a grinding and crushing mill, and that "the measurements made so far should be regarded as of a preliminary nature."

A summary of the results is as follows:

Driving Machines compared:

5-h.p. portable electric motor.

6-h.p. portable Diesel engine.

Fuel costs:

Electricity, 1·42*d.* per unit.

Diesel fuel, 8¼*d.* per gallon.

Lubricating oil as for tractor.

Life and maintenance of machines (estimated):

Motor—Life, 20 years; depreciation, 7½ per cent.; maintenance, 2 per cent. of original cost (i.e. 2 per cent. of £37 10*s.*).

Circuit—Life, 25 years; depreciation, 7½ per cent.; maintenance 2½, per cent. of £5.

Engine—Life, 10 years; depreciation, 15 per cent.; maintenance, 5 per cent. of £73.

Comparative costs for the same operation:

Electric Motor and Equipment:	d.
Electricity cost	6·50
Overheads	1·75
Total	8·25

Diesel Engine:	d.
Fuel and lubricating oil	2·50
Overheads	5·50
Total	8·00

This seems to indicate that the Diesel is slightly cheaper than electric drive with electricity at 1·42*d.* per unit. The costs would have been equal with electricity at 1·36*d.* per unit.

Summarizing the results of the grinding experiments, the report states that " in view of the preliminary nature of the experimental results and the somewhat arbitrary assumptions necessarily made in various overhead items of cost, it is fairer to say that at present there seems little to choose between the 6-h.p. Diesel and the 5-h.p. electric motor."

In determining the costs in these experiments 500 hours of use per annum was assumed.

2. Pumping

As an adequate water supply is essential both on farms and in country houses, the question of pumping is an important one. The water required averages from 10 to 20 gallons per day per person, and about the same amount per horse or cow per day. Smaller animals, such as pigs or sheep, may require 1 or 2 gallons each per day.

The electric motor is ideally suited to this type of work, and the pumping may be automatically controlled by using a float switch, which is operated by the rise and fall of the water in the storage tank. This switches off the motor when the tank is nearly full and switches on again when the water level falls.

There are several designs and types of pump available, the choice depending upon the lift and rate of delivery required. A detailed examination of these would be out of place here,[1] but, in general, for delivering small quantities of water to a considerable height, piston pumps are best. These may be single-cylinder or double-acting, and of either low or high speed.

The horse-power of the driving motor necessary depends upon the depth of the well and rate of delivery, and varies from about $\frac{1}{6}$ or $\frac{1}{4}$ h.p. for a depth up to 20 feet and delivery of 100 to 200 gallons per hour to $\frac{1}{2}$ to $\frac{3}{4}$ h.p. for 20 to 50 feet and 200 to 300 gallons per hour. Horse-powers up to 3 may be required for greater depths. The electric power consumption for all but the very deep wells may be taken, therefore, as from 200 to 800 watts, and the delivery per unit of electricity as from 500 to 1,500 gallons.

In the case of a newly installed pump to be electrically driven, the motor and pump may be direct-coupled and mounted on a bedplate as shown in Fig. 36 or a combined motor-pump unit may be installed, the pump being mounted on the frame of the motor as in Fig. 37.

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[1] See *Pumps for Farm Water Supplies*, by C. A. Cameron Brown (published by Oxford University Institute of Research in Agricultural Engineering), for further information on this subject.

For the conversion of an established pump to electric drive a belt drive from the motor may be used, or, in the case of force pumps, the motor may be made to drive through gearing and a crank attached to the pump handle. For occasional pumping a portable motor, which can be taken to the pump, or a portable motor-pump unit can be used.

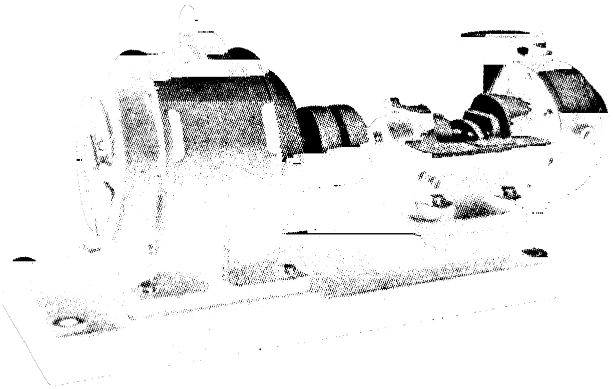

FIG. 36.—DIRECT-COUPLED MOTOR-PUMP UNIT.
By courtesy of Metropolitan-Vickers Electrical Co., Ltd.

The initial costs of motor-driven pumps are from £12 upwards, according to the size and auxiliary equipment required.

In addition to their use for the normal water supply, these pumps may be used for irrigation and for the spraying of fruit trees either through a pipe system fed from a central pump, or by self-contained spraying machines which may be electrically driven.

Another application is the liquid-manure pump. On farms where a large number of animals are kept, it is useful to be able to collect the liquid manure in an underground

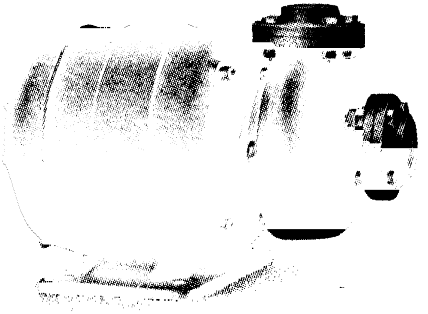

FIG. 37.—COMBINED MOTOR-PUMP UNIT FOR FARM USE.
By courtesy of Metropolitan-Vickers Electrical Co., Ltd.

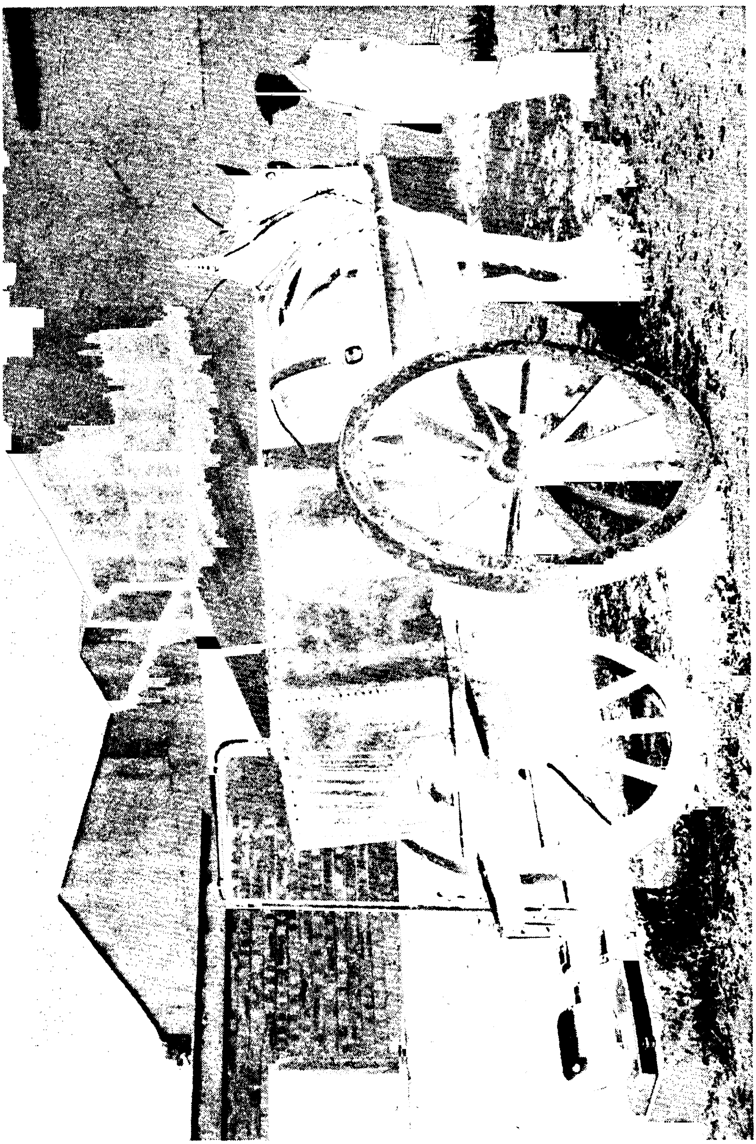

Fig. 38.—Electrically Driven Liquid-manure Pump.

By courtesy of the General Electric Co., Ltd.

tank from which it may be pumped into a tank mounted on a cart for transportation to the field. A small ½-h.p. motor is very satisfactory for this purpose, but the design of the pump must be such that it is not choked by any solid matter contained in the manure.

3. Dairy Work

For dairy work electricity is especially valuable because in all its applications it has the characteristics of cleanliness and absence of fumes. The horse-powers required for most machines associated with this work are usually quite small, so that the consumption costs are not likely to be a serious item, whatever the price of electricity. In addition to the above-mentioned advantages, therefore, the convenience, reliability, and low maintenance should be convincing arguments in favour of electrical operation. A brief review of the applications to dairy work is given below.

(*a*) *External to the Dairy*

Lighting in Cowsheds.—Good light is essential if clean milk is to be obtained. The lighting question has already been discussed in general. For efficient lighting in cowsheds, dispersive reflectors should be used with 60-watt pearl lamps, the fittings being arranged to avoid dazzle and to throw light on to the hind-quarters of the cow. If inspection lamps are thought necessary wall plugs should be provided, and these should be combined with a transformer to reduce the voltage to a low value such as 25 volts, as this is safer than the normal pressure of about 200 volts, owing to the floor probably being wet.

Small transformers for this purpose, having an earthed metal barrier between the high- and low-voltage windings, as well as ample insulation of the windings to eliminate any risk of shock, are available in two designs—one for wall mounting and one a portable form. The output of these transformers is 60 watts, so that two 30-watt lamps can be supplied from each, and the price of the transformer is £2 15*s*. (for wall mounting) or £3 18*s*. (for portable form).

Milking Machines.—Although milking machines have not in the past found much favour in this country, the prejudice against them is gradually disappearing (in Great Britain there are now over 4,000 milking machines of one make alone in use), and it is likely that the considerable number of farmers changing over to production of Grade A milk will lead to the increased use of these machines, which undoubtedly assist compliance with the requirements of such production. Mention should be made of the combine milkers, which, in addition to milking, record, inspect, weigh, and convey the milk from the cow to the bottles as well as equalizing the butter fats in the churns. In New Zealand more than 10,000 electrically driven milking machines are in use.

Two general types are available. For small herds of 12 or 15 cows a portable milker, illustrated in Fig. 39, is suitable. A ½-h.p. motor, supplied from a wall plug, is carried on the truck upon which the milking machine is mounted.

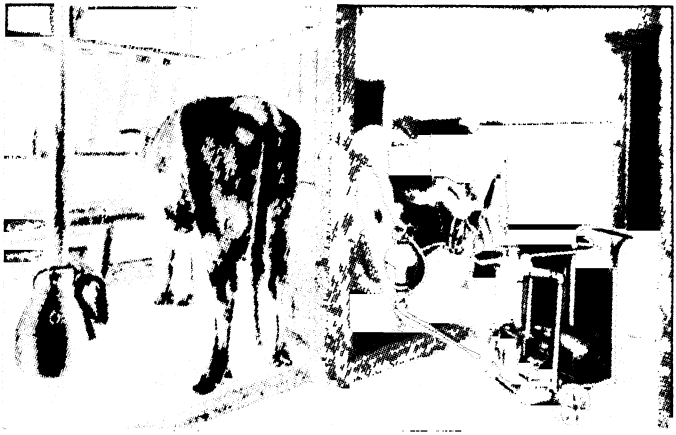

FIG. 39.—PORTABLE MILKER DRIVEN BY A ½-H.P. MOTOR.

By courtesy of the General Electric Co., Ltd.

For larger herds a pipe-line equipment (see Fig. 40) operated by a vacuum pump is more suitable. A 1- or 2-h.p. motor is necessary to drive this pump.

The prices of these machines are : Pipe-line equipment costs vary with the length of piping required, the number of cows to be milked, and number of milking units required. The complete cost for such an equipment for a herd of 10 cows, including two milking units, phosphor-bronze spare pail, combined sanitary trap, vacuum controller, and vacuum gauge, rotary pump and motor, 40 feet of pipe work, and erection, is £70. Hire-purchase terms of from 25*s*. per week are available for certain makes of milking machines.

The running costs, with electricity at 1*d*. per unit, are from ¼*d*. to ¾*d*. per cow per week, the lower cost being for the larger herds.

Stripping by hand is advisable after removing the milker from the cow, but the saving in labour and time is considerable. As an example, figures given for a Cheshire farm with an electric milking machine show that 90 cows are milked in 1½ hours by 6 men, 3 of whom are washing, stripping, or drawing fore milk, whereas at least 10 men would be required without the machine. Again, with 10 milking units, 120 to 130 cows can be milked in 1½ hours, using 6 or 7 men instead of 10 to 12 for hand milking. Cleaning the machine requires half an hour per day, with half a day once or twice a week for dismantling.

FIG. 40.—PIPE-LINE MILKING EQUIPMENT.
By courtesy of Alfa-Laval Co., Ltd.

Groomers and Clipping Machines.—These machines are very useful for keeping cows in a clean and healthy condition, and are especially necessary in Grade A or Certified Milk production. The groomers are somewhat similar in operation to the domestic vacuum-cleaner and are very convenient to use, as they can be strapped on the back of the operator. The motor is of fractional horse-power, so that the consumption is usually less than 200 watts and the device may be connected to a lighting circuit if necessary. The cable supplying the machine should have an earth core to avoid risk of shock. The cost of these machines is about £12. An electrically driven machine with interchangeable heads for clipping or shearing and having a power consumption of less than 100 watts may be obtained for less than £10.

(*b*) *Within the Dairy*

The number of appliances within the dairy itself which may profitably be electrically operated is large, and it is impossible to discuss these in detail in the space available here. In all dairies a plentiful supply of hot water is necessary and may be obtained by electric water heaters of various types, such as were discussed in the preceding chapter. Electrically operated sterilizing chests for dairy utensils are very convenient and economical, and these are coming to the fore with the increase in high-grade milk production. Messrs. Aveling-Barford recommend that, after washing and rinsing, milk bottles should be put in a sterilizing chest, the temperature being brought up gradually to 210° F. and maintained at this value for 10 minutes. Refrigeration for storage of cream and milk and for the cooling of milk is also an important application. For power purposes line shafting may be used, although the small size of the motors necessary for the drive of most dairy appliances renders the objection of high initial cost of individual drive less serious than in other branches of farm work, and this method of drive is perhaps more common than by line shafting.

Most of the commoner applications within the dairy are given in the table below, together with the energy consumption, horsepower or watts loading, and other relevant information. Certain of these are more suited to the large-scale dairy than to the normal-sized farm dairy, but they are included for completeness.

Interesting information has been given[1] for combined consumption costs in a dairy dealing with 60 gallons of milk and 300 bottles daily. Thus, with a tariff of 1*d.* per unit for motor power and ¾*d.* per unit for steam and hot-water production, the daily costs were found to be as follows :

	Daily cost.	
	s.	*d.*
For sterilizing and water heating . . .	1	11½
For cooling, separating, bottle cleaning, and cold storage		5½
Meter rents		1
	2	6

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[1] *Osram G.E.C. Bulletin*, December 1933.

TABLE XXIII

DAIRY EQUIPMENT

Appliance or operation.	H.p. or kilowatts loading.	Output for a consumption of 1 unit of electricity.	Costs at 1*d.* per unit.	Work done per hour.	Notes
Milk cooler .	¾–5 h.p.	30–50 gal.	½*d.* for 20 gal.	40 gal.	" Ethylor " cooling plant, using ethyl chloride at a pressure of only 8–12 lb. per square inch. Safe to use and skilled attention unnecessary. Can be sterilized in place. Milk cooled to 40° F. immediately upon switching on.
Churn . .	⅛–2 h.p.	100–150lb. of butter	½*d.* for 60 lb.	150 lb.	See Fig. 41.
Separator .	⅛–2 h.p.	150–250 gal.	½*d.* for 100 gal.	15–120 gal.	
Sterilizing chest	4–12 kW	4–12 units per operation	8*d.* per operation	—	Chest 3 × 4 × 4 feet has loading of 8 kW. When sterilizing utensils, the operation takes 1 hour (starting with cold water) with a consumption of 8 units. When sterilizing bottles, 1½ hours and 12 units. Initial cost of this size chest, £54 10*s.* (see Fig. 42). Cheaper chests (down to £7 15*s.*) are obtainable.
Bottle washer.	⅛–¾ h.p.	2,000 bottles	½*d.* for 500 bottles	1,000 bottles per hour upwards	See Fig. 43. Initial cost, with motor, £12 for single brush, £14 for double brush. For machine driven from line shafting, £3 10*s.* to £5 5*s.*
Milk bottling .	½–1½ h.p.	2,000 bottles	½*d.* for 1,000 bottles	1,000–3,000 bottles per hour	—
Cheese curd grinding	½–1 h.p.	6 cwt.	½*d.* for 3 cwt.	—	—
Pasteurizing .	¼–½ h.p. (driving agitator)	200–600 gal.	½*d.* per hour	Up to 600 gal. per hour	—

These costs were derived from observation during 13 weeks, the weather being hot, so that the cooling and cold-storage plant were in full operation.

4. Poultry Farming

The poultry-farming industry, which has made such rapid progress during the last decade that the total annual value of eggs and poultry produced in Great Britain and Northern Ireland is now estimated to be greater than the annual value of all the cereals produced in the country, provides a wide field for the application of electricity. The intensive competition from both home and foreign producers compels the poultry farmer, if he is to be successful, to adopt labour-saving devices to the utmost extent, and many of these are either exclusively electrical or can be operated most economically by electricity.

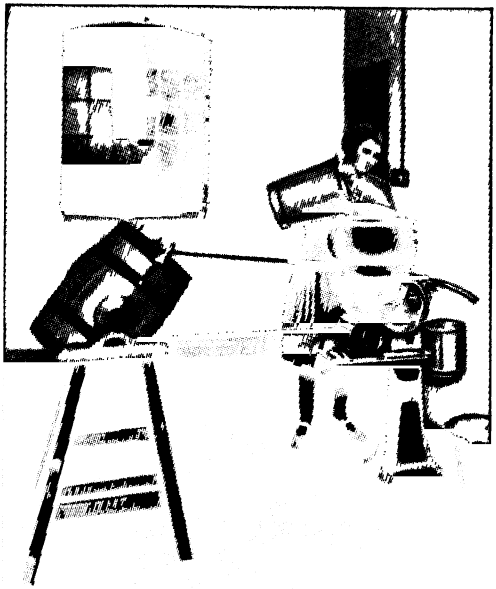

FIG. 41.—MOTOR-DRIVEN CREAM SEPARATOR AND CHURN.
By courtesy of the General Electric Co., Ltd.

Briefly, the electrical applications are to lighting and heating (in competition with oil, to which electricity has already been shown to be superior from the points of view both of economy and convenience) and to small power purposes for which an electric drive is usually the only feasible one. A poultry farm being generally less extensive and less scattered than other types of farms, the difficulty of distribution of electricity to the points at which it is to be used becomes much less serious. From the supply company's point of view the load is an attractive one, having a good load factor and a high potential consumption of energy. Although individually

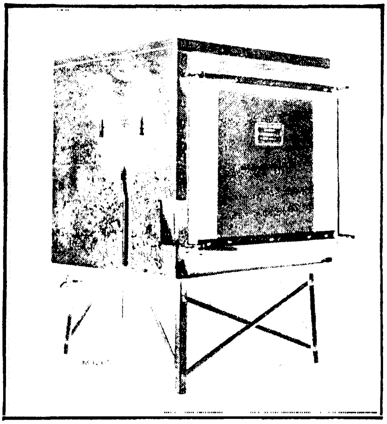

FIG. 42.—STERILIZING CHEST.

By courtesy of Aveling-Barford, Ltd.

the appliances used may have a low watts loading, in the aggregate the installed capacity and energy consumption are considerable. There are, for example, poultry farms having an installed capacity of 50 kW and over and consuming from 10,000 units per annum upwards.

Some brief notes on the various applications will now be given, and these will be followed by a table giving working costs, wattages, and other data.

(*a*) *Incubators*.—These may be divided into: (i) small-size incubators (100–400 eggs), in which oil-lamp heaters are replaced by suitable electric heating elements in both hot-air and hot-

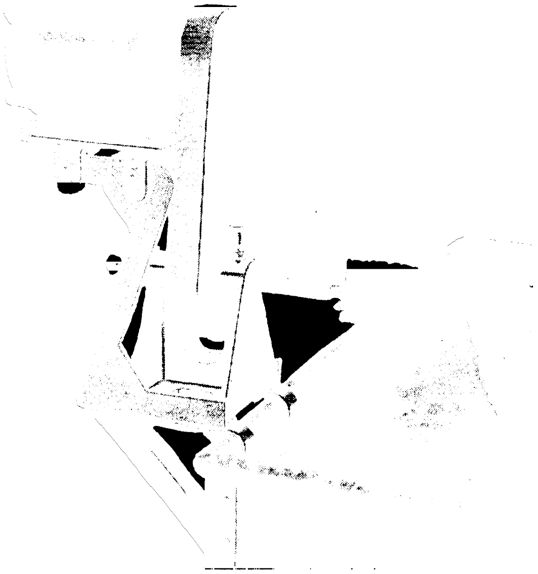

FIG. 43.—BOTTLE WASHER.

By courtesy of Aveling-Barford, Ltd.

water tank types ; (ii) mammoth incubators (500–70,000 eggs), in which electric heaters and electrically driven fans, for air circulation, are used. There is an increasing tendency towards the use of these large incubators by a small number of large-scale producers of day-old chicks. Such chicks are purchased by the smaller poultry farmers for rearing purposes instead of their hatching their own chicks by small-size incubators. It is stated that mammoth incubators produce heavier chicks and a greater percentage hatching than the smaller size. They are also more economical in energy consumption per chick.

In both types the temperature—100° to 103° F.—is thermostatically controlled to within $\frac{1}{2}$° F., this being a great advantage as well as reducing energy consumption. In the smaller incubators, whether oil or electrically heated, the capsule type of temperature regulator is often employed. With oil heating the regulation is effected by raising the damper to allow surplus heat to escape. With electric heating the supply is cut off by the regulator when the temperature becomes excessive.

Other advantages are the absence of fumes and of absorption of the oxygen in the incubator room. Fire risks are absent, and the labour of filling and trimming lamps is eliminated. The question of failure of the electric supply may be dismissed with the statement that such failures are comparatively rare and seldom last longer than a few minutes, while the heat capacity of most incubators is such that the supply may be switched off for several hours without any ill effects. Mammoth incubators may be fitted with two thermostats giving dual control at two slightly different temperatures. An alarm circuit may also be fitted, the bell being operated by an electric battery. This gives the alarm in the event of failure of the supply or of excessive temperature. Another important point in favour of electrically operated incubators is their smaller dimensions.

In the case of existing oil-heated incubators, conversion to electric heating can be carried out quite simply at a cost (for the small-size incubators) of from £3 to £5. Apart from the advantages mentioned above, electric heating for incubators is cheaper than oil heating if the cost of electricity is 1*d*. per unit or less. Actual energy consumptions for electrically heated incubators of different sizes are given in Table XXIV, p. 175.

(*b*) *Brooders, Hovers, and Foster-mothers*.—As with incubators, electric heating of brooders has the advantages of cheapness in running costs, convenience, saving of labour and time in attending to oil lamps, reliability, and absence of fumes. Another advantage in this case is the fact that the required heating can be supplied from above, thus saving the space occupied by a lamp in the smaller types of brooder and avoiding the crowding of the chicks round the lamp with consequent overheating.

Several methods of heating are in use. There seems little to choose between them in the matter of costs, either as regards initial capital cost or running cost, so that the one to be adopted depends largely upon the individual preference of the poultry farmer. The two general methods are:

(i) Lamp heating by means of four carbon-filament lamps (16 or 32 candle-power) in a special holder fitted to the lid or cover of the brooder. Two switches are provided to give low, medium, or full heat by switching lamps on and off. Some poultry keepers object to the light for the chicks, but it has never been proved to be detrimental, and a large number of such brooders are in use. They have the advantage of simplicity both in construction and as regards replacement in the event of failure or breakage.

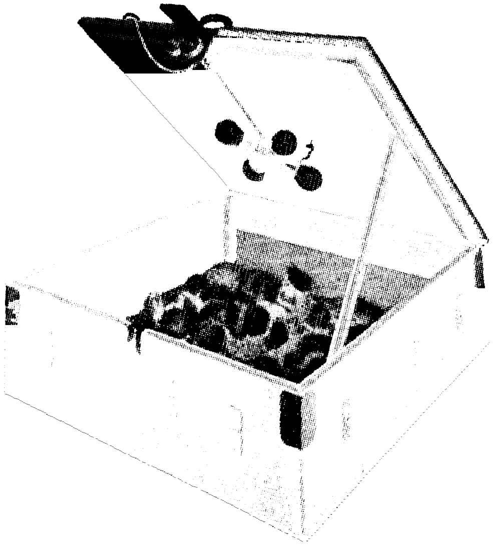

FIG. 44.—RADIANT ELECTRIC HOVER.

By courtesy of the General Electric Co., Ltd.

(ii) Heater elements of either the radiant type (somewhat similar to the domestic electric fire) or of the dull-heat type in the form of mats, plates, or tubes. These elements may be fixed to the lid of the brooder or, in the case of an open brooder, suspended by chains above the chicks. Temperature control is provided by switching to give four- or six-heat control or, in some makes, as many as twelve heats. Thermostatic control of temperature is often used, but this is not really essential, and multi-switch control is sometimes relied upon.

The modern tendency is to rear large numbers of chicks indoors, and battery brooders are used to save space. In this case the brooders are placed in tiers, each tier being heated by a separate heating mat. Electrically driven fans are frequently used for circulating the heated and humidified air through the brooder room and for withdrawing foul air. Thermostatic control is more necessary with these mammoth brooders.

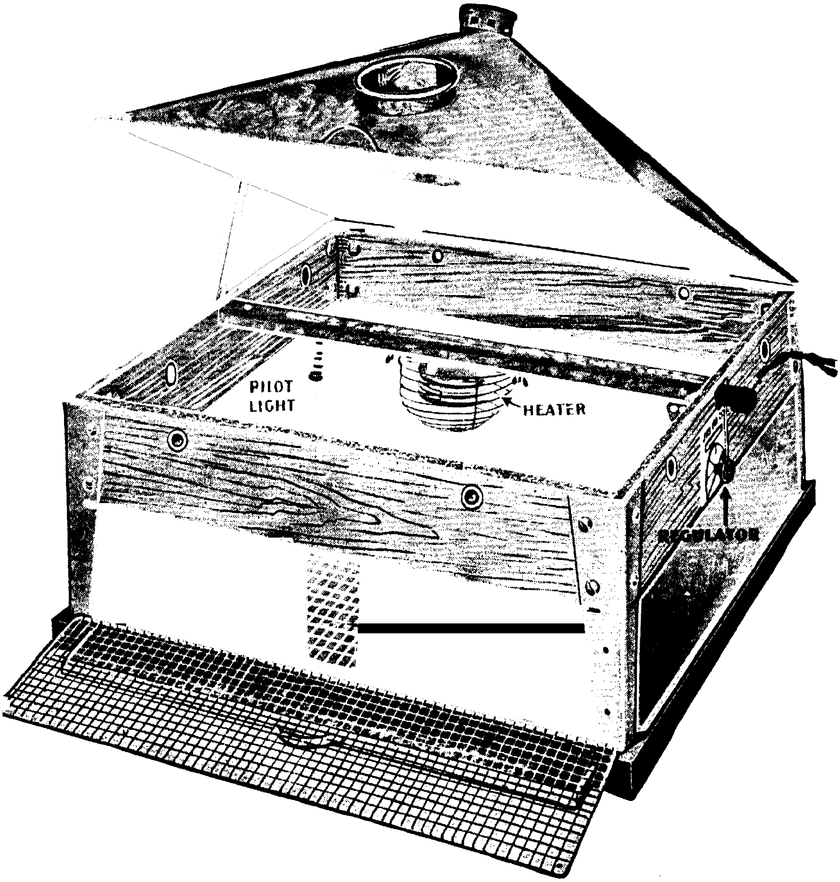

FIG. 45.—THE "VISI-SUNRAY" ELECTRIC BROODER.

By courtesy of the Visi Chick Brooder Co.

Outdoor foster-mothers with electric heating are being increasingly used. These have a low-wattage heating element, with multi-switch control of temperature.

Figs. 44–47 show the construction of several types of brooder[1] while information regarding loading and running costs is given in table XXIV.

(*c*) *Egg-testing Lamp.*—The electric egg-testing lamp contains a standard 40- or 60-watt lamp, but the lampholder is designed to give a concentrated beam of light at a small aperture, against which the eggs are held. These are also available for use with a low-voltage (6- or 12-volt) automobile lamp supplied from a battery. The eggs may be tested at the rate of 500 or 600 per hour.

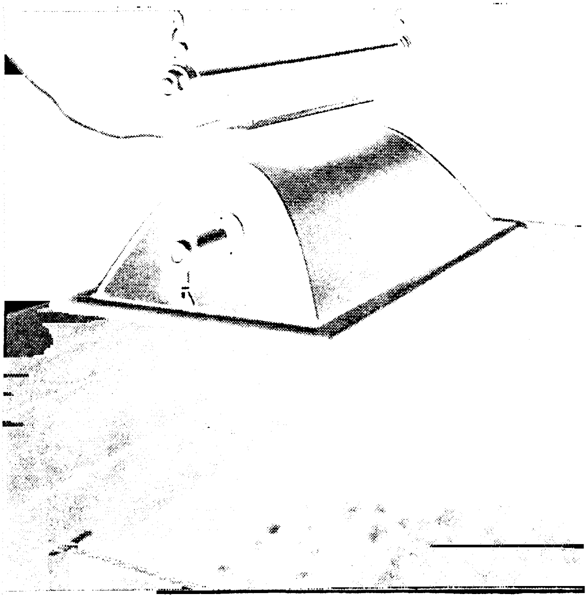

FIG. 46.—THE FERRANTI BROODER.

By courtesy of Ferranti, Limited.

(*d*) *Egg-grading Machines.*—Machines for grading eggs according to weight are not always essential pieces of equipment, but

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[1] Since the description of the various types given above is necessarily very brief, those particularly interested in the subject should refer to the various manufacturers' catalogues and to the following publications for further information: The British Electrical Development Association Inc. (2 Savoy Hill, London, W.C.2) publications, *E.D.A.* *1233* and leaflet on poultry farming; *Rural Electrification and Electro-Farming*, December 1933; *The Electrical Times*, November 29th, 1934.

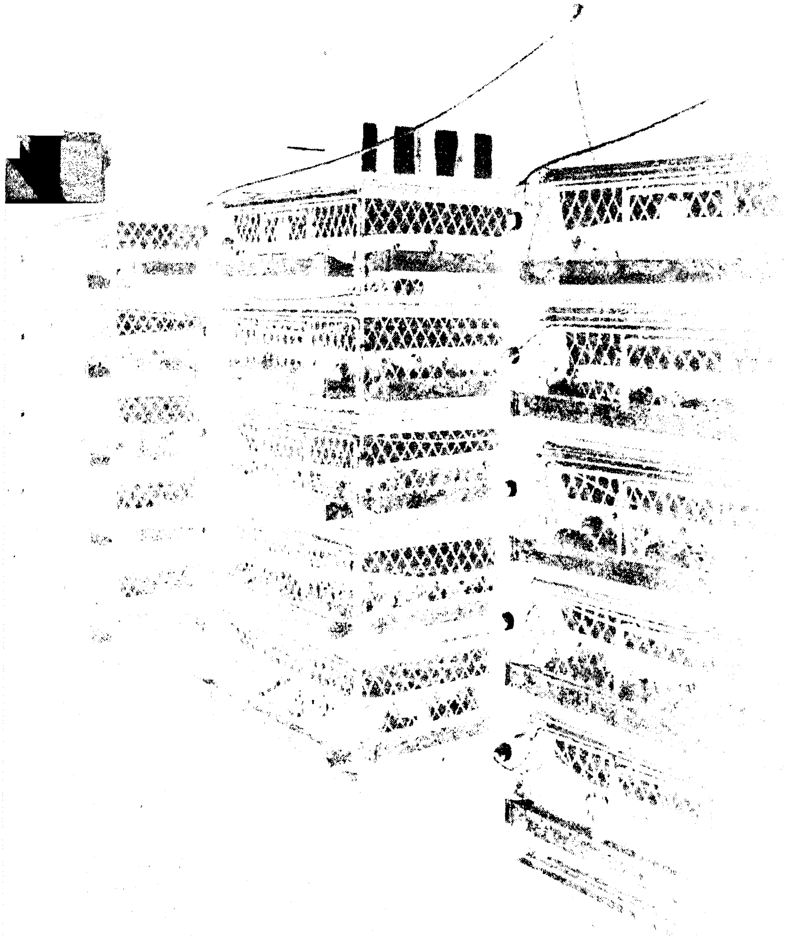

FIG. 47.—MAMMOTH BROODER AT THE ABSOL PARK POULTRY FARM.
(Installation by Mr. E. A. Kett, Saffron Walden.)

By courtesy of the Electrical Development Association.

may be used by the large poultry farmer dealing direct with the customers instead of via a packing station. They are driven by a small motor ($\frac{1}{4}$ to $\frac{1}{2}$ h.p.) and may be operated by a youth or girl, the output varying with size from 1,000 to 6,000 eggs per hour.

(*e*) *Egg-washing Machines.*—A machine for this purpose is illustrated in Fig. 48. It contains a compartment for the washing water, which is heated by an electric immersion heater, and the eggs pass through the body of the machine, which contains specially designed rotating brushes driven by a $\frac{1}{8}$-h.p. low-speed motor. Half of the brushes are for washing and the remainder for drying, so that the eggs emerge on to a wire tray both washed and dried.

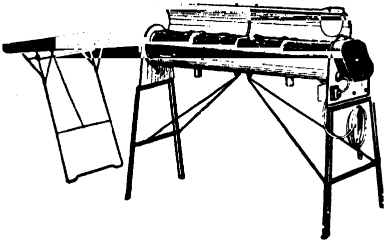

Fig. 48.—The "Summit" All-electric Egg Cleaner.

By courtesy of Cope & Cope, Ltd.

The overall length of the machine, which, it is claimed, will wash and dry 3,000 eggs per hour, is 7 feet, and its cost £21 for A.C. or D.C. supply.

(*f*) *Poultry-house Lighting.*—Electric lighting in the poultry houses can be used to lengthen the effective day for the hens and so give an increased time for feeding. This is necessary during the winter months, since otherwise the feeding time is too short to enable the hens to obtain adequate amounts of food and exercise when they most need them. Such lighting, using one of the systems mentioned below, has been used successfully for both egg production and the raising of birds for table use.

As regards egg production, it is found that the hens do not lay, throughout the year, many more eggs if winter lighting is used, but the eggs are produced when the price is higher, and so are more profitable. This lighting is usually continued from September to January or February. Increased feeding time enables table birds to put on weight more rapidly. Throughout the winter the energy consumption for this lighting is only about $\frac{3}{4}$ unit per bird, and even when the cost of installation and that of the extra food eaten by the birds are taken into acount, the increased prices obtained for the eggs make it profitable, even if electricity costs several pence per unit.

Turning to the equipment and methods used, the lamps are often 40-watt pearl, and dispersive reflectors are used to give correct distribution of the light. The lamps should be arranged

TABLE XXIV

Poultry-farming Equipment

Appliance.	H.p. or kilowatts loading.	Consumption (units of electricity).	Running costs at 1*d*. per unit.	Notes.
Incubator (100- to 400- egg sizes	200 watts	$\frac{1}{5}$–$\frac{1}{4}$ unit per egg in 21 days	$\frac{1}{4}$*d*. per egg in 21 days	Capital cost, £5 to £16. Usually same cost for either oil or electric heating. About 10*s*. extra for hot-water type.
Mammoth . .	$\frac{3}{4}$–3 kW (fans and heaters)	$\frac{1}{30}$–$\frac{1}{10}$ unit per egg in 21 days	$\frac{1}{30}$*d*.–$\frac{1}{10}$*d*. per egg in 21 days	Capital cost, £30 to £400 (for 20,000-egg size).
Brooder, small (up to 300 chicks)	200–600 watts	$\frac{1}{2}$–$\frac{3}{4}$ unit per chick in 6 weeks	$\frac{1}{2}$*d*.–$\frac{3}{4}$*d*. per chick for 6 weeks	Capital cost, £2 10*s*. to £6.
Battery brooder	150–300 watts per tier	$\frac{1}{2}$ unit per chick in 6 weeks	$\frac{1}{2}$*d*. per chick for 6 weeks	Capital cost, £15 to £20 per double-tier unit.
Egg-testing lamp	40–60 watts	1 unit per 10,000 eggs	1*d*. per 10,000 eggs	—
Egg-grading machine	$\frac{1}{4}$–$\frac{1}{2}$ h.p.	1 unit per 8,000 eggs	1*d*. per 8,000 eggs	—
Egg-washing machine	$\frac{1}{8}$ h.p.	1 unit per 20,000 eggs	1*d*. per 20,000 eggs	Capital cost, £21.
Poultry-house lighting	Depends on size of house	About 1 unit per bird for the whole winter	—	—
Plucking machine	$\frac{3}{4}$ h.p.	40 birds plucked for 1 unit	—	—
Drinking-water heater	15–100 watts	—	10–60 hours for 1*d*.	Capital cost, 7*s*. 6*d*. to £1.
Food grinder .	2 h.p.	2 units per hour	2*d*. per hour	—
Vacuum-cleaner for poultry house	140 watts	7 hours per unit	$\frac{1}{7}$*d*. per hour	Capital cost, about £12 10*s*.

to illuminate the whole of the floor of the house and also the perches.

Various methods of using the lighting are used, the most common being:

(*a*) Morning lighting only.
(*b*) Evening lighting only.
(*c*) Morning and evening lighting.
(*d*) Short-period lighting in the late evening.

With the first three methods, the lighting extends the feeding time either before dawn or after dusk or both. The fourth method rouses the birds for a meal about 9 p.m., the lighting lasting for 1 to 2 hours.

With all methods some arrangement for dimming the lights to give the effect of sunrise or sunset is desirable. The dimming must be sufficient to send the birds back on to the perches and gives time for them to do so before the lights are extinguished. It is carried out either by inserting a resistance into the lamp circuit or by using a series-parallel or other arrangement of the lamps in conjunction with a suitable switch.

Both the control of the lighting and the dimming may be carried out either automatically or by hand. Time switches are made for this use, and these may be set to operate any required system of switching without attention, thus saving the inconvenience of having to carry out the switching at awkward times.

Other miscellaneous applications of electricity to poultry farming are mentioned in the table on page 175, in which the running costs and other data regarding poultry-farming electrical apparatus are given.

5. Handling and Treatment of Crops

Under this heading one might include such processes as root cutting, threshing, and field operations such as reaping, ploughing, and the like. The first two have been dealt with under a previous section dealing with barn machinery. With regard to field operations, although electricity has been used for these purposes, using a stationary motor at one end of the field and hauling the plough or other machine by wire ropes, as is done in steam ploughing, such methods cannot be said to have been entirely successful on the comparatively small fields in this country. It has been mentioned, in an earlier section of the book, that ploughing by electricity has been carried out for a number of years in France, Italy, and other Continental countries ; but it is perhaps best to say that its adoption in this country must, at least, be postponed until the electrification of agriculture has developed sufficiently to encourage both the farmer and agricultural-machine manufacturer to carry out a further study of the problem. The difficulty in electrifying this work lies not in the process itself but in the amount of auxiliary equipment required to transmit power to the point of use and in the time taken in setting up the haulage gear.

Applications under this heading which are at present proving quite successful are the elevating and conveying of crops in and around the farm buildings and the artificial drying of crops, such as hops, grass, and grain. Refrigeration for the storage of fruit in fruit-growing districts is a further development which is proving a success.

Fig. 49 shows a 1½-h.p. motor mounted on a truck with winch and starter for elevating sacks up to about 3 cwt. in weight.

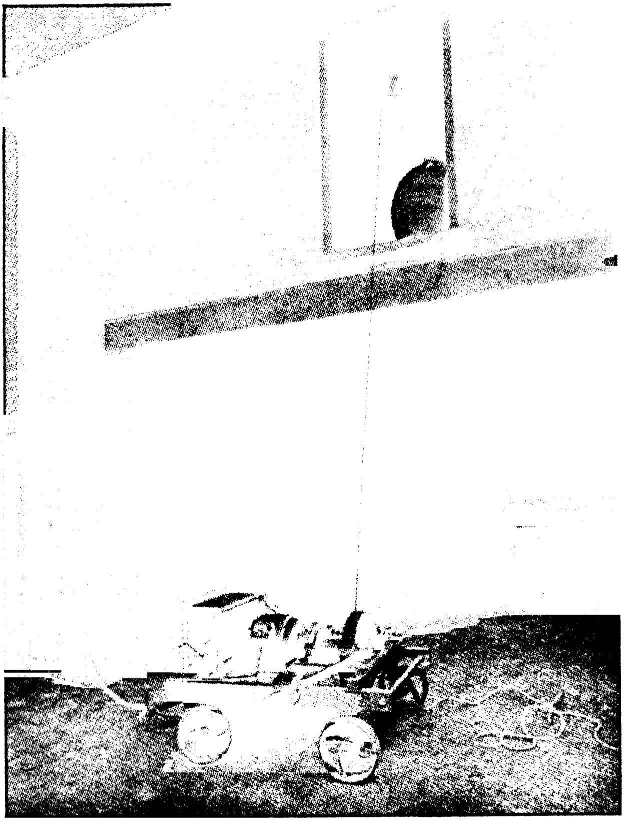

FIG. 49.—ELECTRICALLY DRIVEN SACK HOIST.

By courtesy of Metropolitan-Vickers Electrical Co., Ltd.

It is difficult to estimate the exact energy consumption for this work, since it depends upon the height through which the sacks are raised and upon the auxiliary equipment used. With a motor of this size, however, on full load continuously, the consumption would be only about 2 units per hour.

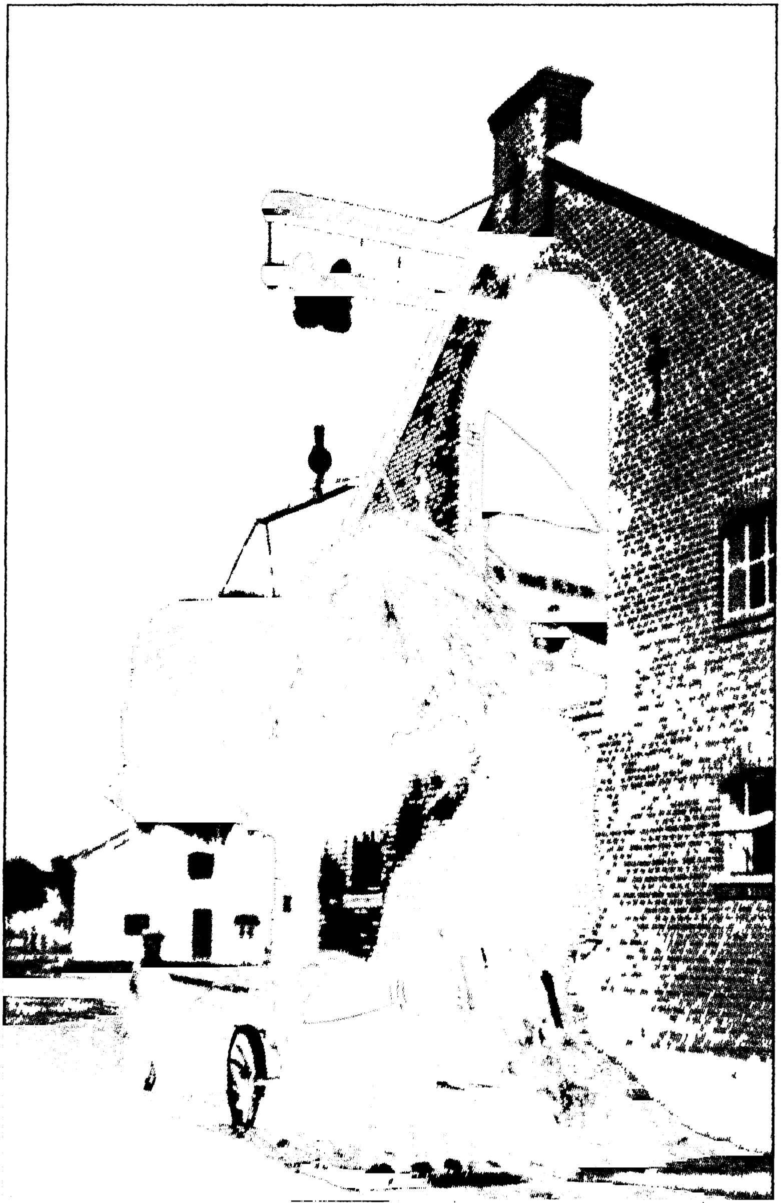

FIG. 50.—ELECTRICALLY OPERATED FODDER HOIST

By courtesy of the Fuller Electrical and Manufacturing Co., Ltd.

A fodder hoist driven by a 3- to 5-h.p. motor is shown in Fig. 50. This lifts the whole load in one hoist. The labour and time saved in unloading hay by this means are very favourable points, especially when the weather is bad and rapid carting of the crop is essential. A runway is also fitted under the roof of the barn so that the load, when lifted, can be carried along for disposition at the required part of the loft.

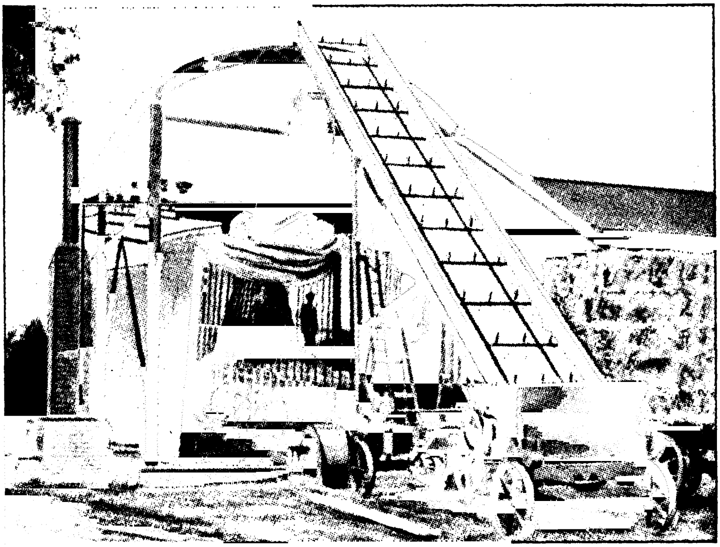

FIG. 51.—ELECTRICALLY OPERATED ELEVATOR AND CROP-DRYING APPARATUS.

By courtesy of Metropolitan-Vickers Electrical Co., Ltd.

In Fig. 51 is illustrated an electrically driven elevator and belt conveyor used, in this instance, in conjunction with a crop-drying equipment. The crop is stacked round a spiral of piping through which warm water is circulated. A small furnace is used for heating the water, while a 7½-h.p. electric motor drives a fan giving a supply of air for ventilation purposes through an underground duct running to the centre of the stack.

A method of crop transportation, which is largely used on the Continent, is by pneumatic conveyors. The produce—straw, grain, chaff, etc.—is blown through the conveyor tubes by a motor-driven fan. In one type the material passes through the blades of the fan, while in another it is inserted through a hopper into the tubes at a point just beyond the outlet of the fan. The second form has the advantage that the crop is not damaged by passage through the fan blades. These conveyor tubes are light, and can be moved into different positions as required without much trouble. The motor required for the fan is from 5 h.p. upwards. Although this method of transportation has not yet been adopted in this country, it would appear to be the most generally useful method for farm purposes, and would be especially useful in threshing operations.

Artificial Drying

In view of our dependence upon good weather for the successful drying of crops, the elimination of risks by the installation of an artificial drying equipment is a procedure which is likely to receive much more attention in the near future. In a recent report of a committee of the Agricultural Research Council, it was estimated that the average loss in making and storing hay in this country is about 25 per cent., representing £5½ millions a year. Several forms of drying equipment are in use, some of which, like the one already mentioned, are for drying out stacks, while others are designed for the drying of grain and for the curing of young grass for feeding purposes.

FIG. 52.—CURING HAY IN THE STACK.

By courtesy of the General Electric Co., Ltd.

A simple equipment of the first type is illustrated in Fig. 52. In this case air is blown along underground ducts leading to a number of outlets under the stack, a 5-h.p. motor being used to drive the centrifugal fan. Above the outlets mentioned, vertical ducts are formed by the use of drums placed over them. These drums are raised as the stack is built, and when finally removed leave vertical ducts about 2 feet in diameter in the stack. Air is blown through for a few hours a day for a period of about 10 days. It is found that the quality of the hay dried by this method is very high, even though the grass is carted almost immediately after cutting. The method is applicable, of course, to cereal crops as well as to hay.

The drying process just described must be regarded as merely a reasonably cheap method of insuring against loss of crops through inclement weather in the harvesting period. The methods described below are entirely different both in procedure and as regards their ultimate purpose.

Drying Young Grass

A large amount of research has been carried out in recent years upon the feeding value of young grass as distinct from hay. The results have shown that the feeding value of such grass is so much greater than that of hay that they must be regarded as quite different foods.

A recent report of a Committee of the Agricultural Research Council[1] has stated it to have been proved, by the various researches carried out, that the dry matter obtained after grass has been cut in the pre-hay stage has " a substantially higher food value than that of hay," and that some method of artificial drying is necessary.

Imperial Chemical Industries, who have prepared a very informative handbook on Grass Drying, have carried out a large amount of work on the subject, and give detailed figures regarding the increased feeding value of this grass. Amongst other conclusions reached as a result of this work and based also upon experiments at Cambridge, Jealott's Hill, and elsewhere, are the following :

(i) More food and more proteins can be grown in the form of young grass than can be obtained from the same area of land by any other crop. This is substantiated by actual yields per acre (expressed in weights of digestible crude protein) for a number of different crops.

(ii) Dried grass can be used to replace concentrates with considerable saving in winter feeding costs.

(iii) The digestibility of the crude protein of fresh grass (84·4 per cent.) is only slightly reduced (to 82·1 per cent.) by drying.

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[1] Privy Council—Agricultural Research Council : A Report by a Committee on *The Preservation of Grass and other Fodder Crops* (A.R.C. Report, Series No. 1, H.M.S.O., 1935).

(iv) The percentage protein equivalent of dried grass compared with hay and with oats is 13 as compared with 4·6 and 7·6 respectively.

(v) Dried grass contains two or three times as much minerals as grains or concentrated feeding-stuffs.

(vi) The most important vitamin value of fresh grass lies in its content of a substance called "carotene," part of which, in the case of the milking cow, passes into the milk and butter, giving the rich colour in summer time. The carotene content of dried grass is only slightly less than that of fresh grass, while for hay it is only about one-twentieth of that of fresh grass.

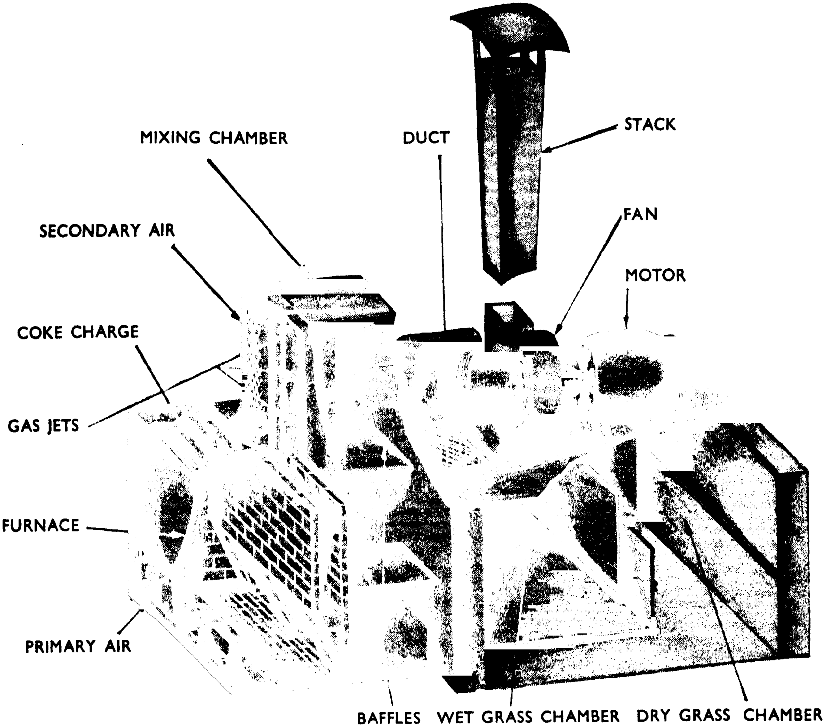

FIG. 53.—SHOWING INTERNAL CONSTRUCTION OF THE BILLINGHAM DRIER.
By courtesy of Imperial Chemical Industries, Ltd.

(vii) Baled dried grass commands a price of £7 to £9 per ton.

The Billingham Drier, in the production of which Imperial Chemical Industries Ltd, and Metropolitan-Vickers Electrical Co., Ltd., have collaborated, is illustrated in Fig. 53. Hot air is drawn upwards by a fan through 24-inch beds of grass laid on trays. The fan is motor driven, while the air is heated by a coke furnace. These driers can handle from 4 to 8 tons of wet grass in 8 hours, the dried grass made in 8 hours being from 21 to 33 cwt. The grass is baled after drying to reduce its bulk.

It is recommended that the grass should be cut at intervals of a few weeks, when it is 5 to 8 inches high. Fertilizers are used to produce the required crops, and the drying process may be made a continuous one, provided the acreage of pasture-land available is sufficient.

The capital cost of these drying equipments is from £500 to £700. They are not, of course, suitable for the very small farmer, although it is possible that they might be purchased and used collectively by a number of smaller farmers in combination. Deferred-payment arrangements can be made.

The costs of production, taking coke at 27*s.* per ton, electricity at ¾*d.* per unit, and manual labour at 8*d.* per hour, are given as £2 to £2 4*s.* per ton of dried grass or, including field work, carting, and fertilizers, £3 8*s.* to £3 12*s.* per ton, the total weights of dried grass during the season to which these costs refer being 200 tons and 320 tons (for two different sizes of driers). Taking the value of dried grass as £7 per ton, the profit in the first two seasons is thus sufficient more than to repay the whole cost of the equipment.

As regards collection of the grass after cutting, the cut-lift system is the most economical as regards labour and it enables cutting to be started in spring at an earlier date than would otherwise be possible, owing to the shortness of the grass. In summer an appreciable saving of drying costs (up to 25 per cent.) may be obtained by allowing the grass to dry in the field for 12 to 24 hours. Although the labour cost of collection is increased somewhat, there is a net gain by so doing. Wilting in this way produces only a small loss of carotene and of protein. The cut-lift system is illustrated in Fig. 53A.

It is interesting to note that the installation of drying equipments do not result in the displacement of manual workers. Actually, more workers are required, the value of the product being sufficiently high to justify their employment. In fact, the net result is that the necessary concentrated feeding-stuffs are produced locally instead of importing them from abroad.

Messrs. Ransomes, Sims & Jefferies manufacture the Davies crop drier under licence granted by British Crop Driers, Ltd. In this drier the grass or grain is conveyed on a moving band of bars. A coke-fired furnace supplies hot gases for the drying, and these

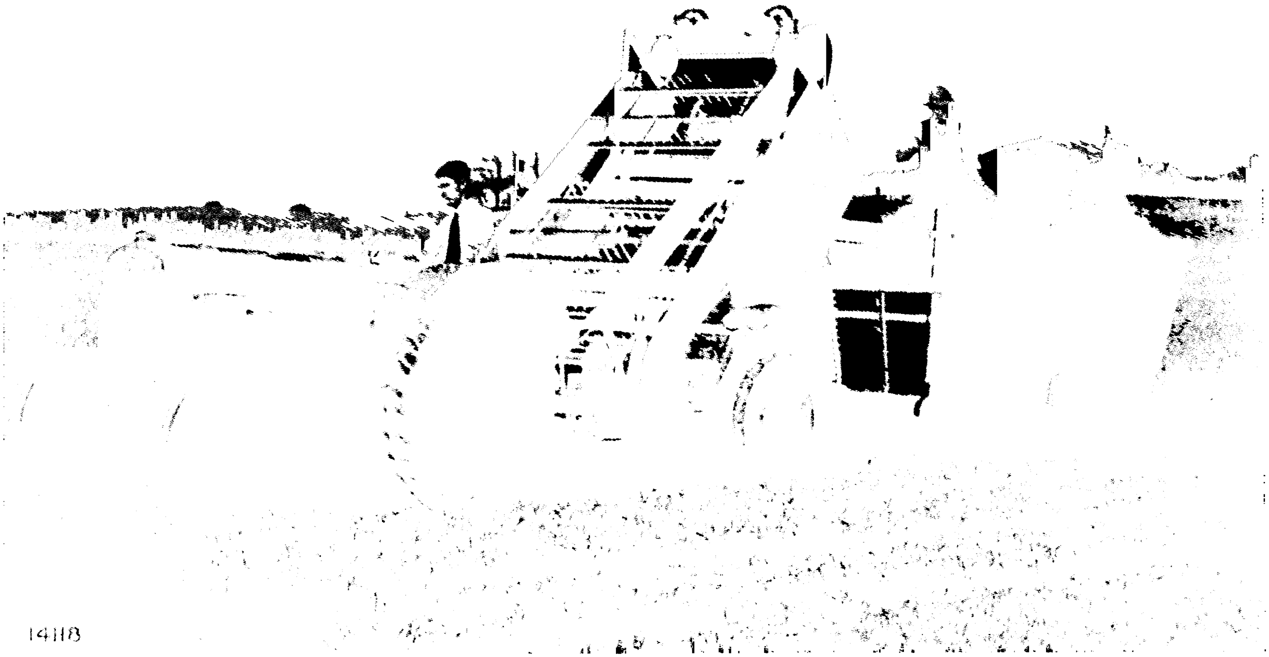

Fig 53A —Wilder's "Cut-lift" Elevator used in conjunction with a Hornsby Mower

By courtesy of Ransomes Sims & Jefferies Ltd gases are driven through the crop by two motor-driven fans. The drier can be arranged for grass only, for grain only, or it may be a dual-purpose machine. The initial costs of the equipment range from £240 (for grain only—£490 for a dual-purpose machine) to £1,375 (dual purpose) according to size.

In the smallest size the output of dried grain is 1 ton per hour, the fuel consumption being 40 to 60 lb. of coke per hour and the horse-power required from the driving motor being 10. In the largest size the figures are :

Output : grain, 3 to 4 tons per hour ; grass, 7 to 8 cwt. per hour.

Fuel consumption : grain, 180 to 240 lb. of coke per hour ; grass, about 400 lb. of coke per hour. H.p. required, 36.

A large-scale equipment erected at South Acre, Norfolk, has dealt with 12,000 tons of green crop (from 2,000 acres) in a season, producing 3,000 tons of dry lucerne. The equipment is capable of dealing with 30,000 tons of freshly cut lucerne in a season.

In the case of grain, some of the advantages claimed for artificial drying are :

(i) The possibility of working to a schedule instead of waiting for suitable weather.

(ii) Considerable saving in shedding of grain and losses due to birds while the crop is drying in the field.

(iii) The grain may be harvested, dried, and bagged in one day instead of keeping it in the stack until threshed, it being assumed that either a combine harvester is used or that the crop is threshed direct from the field.

(iv) The drying may be controlled so that the moisture content is exactly that required for storage purposes. The grain is thus in good condition when sold for either seed or milling.

Incidentally, it has been proved that artificial drying does not impair germination. Fig. 54 shows a Davies drier arranged for grain drying, the furnace being just visible beyond the two motor-driven fans on the left.

Hop Drying

Electricity has been adopted successfully in a number of places for the drying of hops. For this purpose motor-driven exhaust fans are used for circulation of the hot air and removal of the moisture, a blower fan also being used to blow the air over the heaters. The furnace for heating the air may be oil-fired, or electric heaters may be used. Although, depending on the electricity tariff, electric heaters may be rather more expensive to run, the heating cost is not a very important item in the produc-

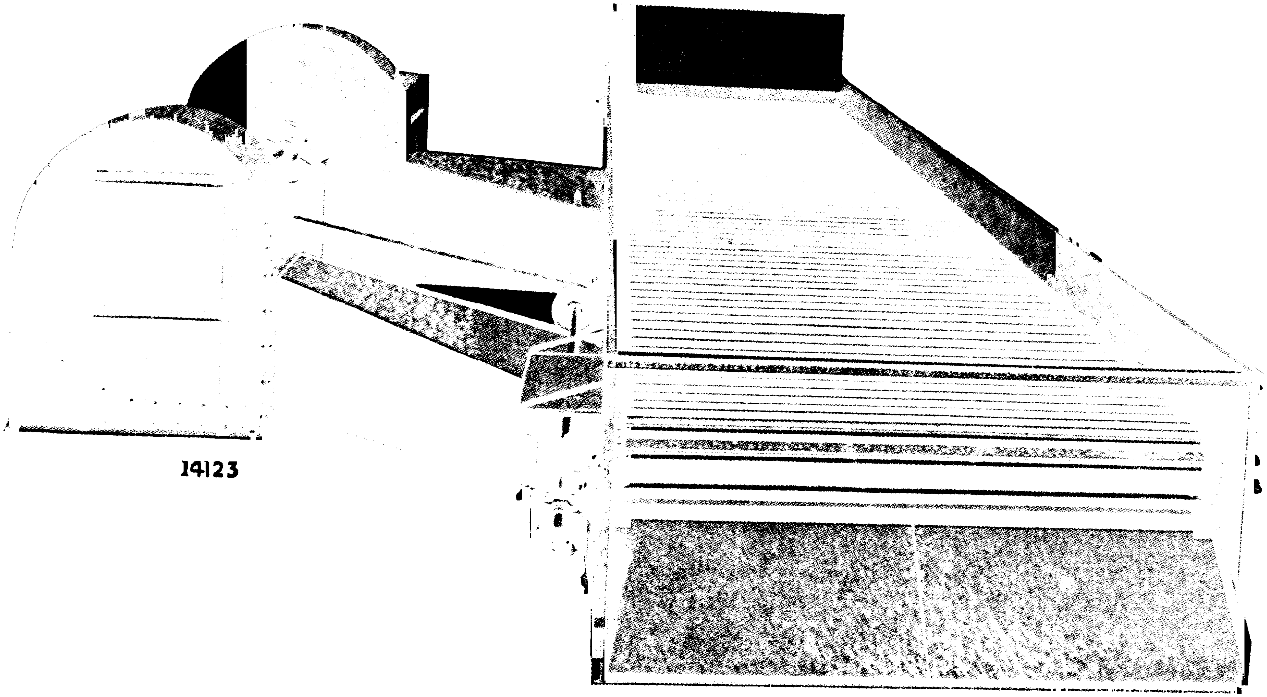

FIG. 54.—DAVIES DRIER ARRANGED FOR GRAIN DRYING.

By courtesy of Ransomes, Sims & Jefferies, Ltd.

tion, and the electric method has the advantages of absence of dirt or fumes, lower initial and maintenance costs, and greater simplicity of control.

An interesting account has been given[1] of an electrified hop and fruit farm in Kent on which, in addition to the use of electricity for hop drying as mentioned above, a 10-h.p. electric motor is used to drive pumps supplying some 8 miles of piping with a solution for spraying the fruit trees. One man can spray 5 acres a day with this equipment. A motor-driven apple grader is also used, and electricity is used for sheep-shearing, watering the stock, and for lighting, cooking, and heating within the farm-house. The total annual consumption of electricity is of the order of 12,000 units.

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[1] *Electrical Review*, September 21st, 1934.

CHAPTER IX

APPLICATION TO HORTICULTURAL WORK

FOR horticultural purposes the advantages of electricity are probably greater than for ordinary farm work, while the problem of economical electrification is much more easily solved. The main reasons for this are as follows :

(i) Being an intensive form of cultivation in which competition is fairly severe, any labour-saving device is to be welcomed.

(ii) The prices of the products are sufficiently high to justify some expenditure for electrification, provided it is likely to be profitable.

(iii) Horticultural holdings are usually sufficiently compact for the cost of distribution to the various points of use to be kept reasonably small.

(iv) Such holdings are often situated at no great distance from an urban district, so that the transmission costs to the supply undertaking, and therefore the price of electricity to the consumer, are likely to be less than is the case in the more distant rural districts.

From the supply company's point of view the horticultural load must be regarded as a satisfactory one, since several of the applications involve either the continuous use of electricity or its use during the night. Such a load tends, therefore, to increase the load factor of the system. Again, in addition to various labour-saving devices, electric heaters may be used to accelerate cropping, and this is a very important matter, since higher prices may be obtained for an early crop.

In addition to electric light for general purposes, the following applications of electricity to horticultural work are available :

(i) Motor-driven pumps for water supply.
(ii) Soil-heating cables.
(iii) Greenhouse heaters.
(iv) Water heaters for the provision of warm water for plants.
(v) Soil-sterilizing equipment.
(vi) Electric lamps for intensive illumination.
(vii) Insect traps.

(viii) Fans for air circulation.
(ix) Electrically driven water sprayers.
(x) Electrically driven rotary tillers and lawn mowers.

The more important of these are discussed below.

Soil-heating Cables

After a considerable amount of research and development work soil-heating cables, which are for the purpose of providing " bottom heat " in frames, greenhouses, and open beds, are now on the market and are found to give highly satisfactory results. As long ago as 1926, soil heating was widely employed in Norway and Sweden, while in 1930 more than 5,000 frames in Norway were heated in this way. Although not yet so widely known or appreciated in this country as they deserve to be, there is no doubt that such cables are well past the purely experimental stage and, with the increasing scarcity of animal manures for the production of heat, they should soon be much more widely used.

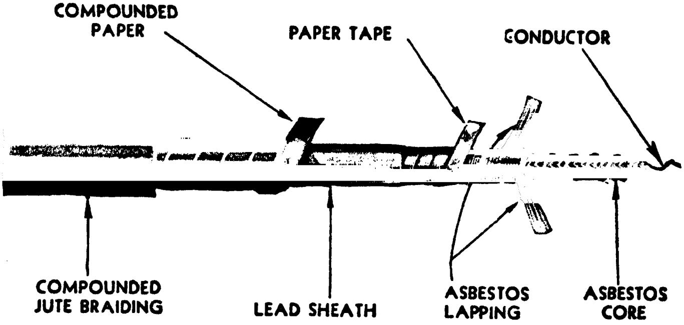

FIG. 55.—CONSTRUCTION OF SOIL-HEATING CABLE.
By courtesy of the General Electric Co., Ltd.

They have the advantages, compared with horse-manure, of much greater control of the soil temperature, as well as a saving of labour in carting and laying the manure in the beds. Hot-water pipes, also, are inferior to these cables as regards control of temperature and in the labour costs involved in attending to the furnace.

The cables themselves consist of high-resistance wire electrically, mechanically, and chemically protected by suitable wrapping, the construction of one form being shown in Fig. 55. As alternatives, bare galvanized iron wires laid in the soil and supplied at low voltage from a transformer, and also two electrodes placed in the ground so that the current is passed through the soil itself, have been used with some success, although the insulated cable shown is the most usual method.

For economical usage some heat insulation is required, the construction of the bed being as shown in Fig. 56. The soil of the bed is laid about 8 inches deep on a foundation of about 1-foot thickness of coke or ashes, over which is a 1- or 2-inch covering of sand, in which the cables themselves are laid. Wire-netting may be laid on top of the sand for further protection of the cables when digging operations are carried out. The heat-insulating material may be built up round the sides in the case of a frame, waste cork (if obtainable) being excellent for this purpose. The cables are laid several inches (up to 1 foot) apart, the spacing being less near the outside of the bed to allow for increased conduction of heat to the outside. If two cables are used (in which case two-heat control is possible by switching on one or both of the cables), these should be

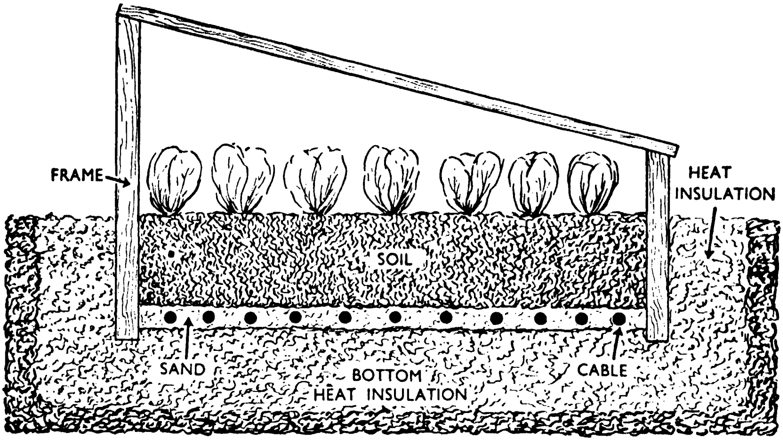

FIG. 56.—FRAME WITH ELECTRIC SOIL-HEATING CABLES.
By courtesy of the General Electric Co., Ltd.

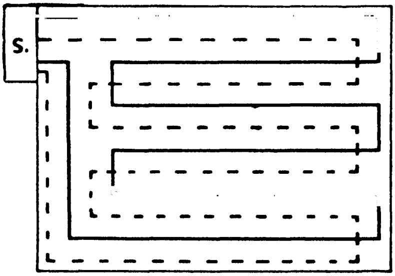

FIG. 57.—LAYOUT OF TWO SOIL-HEATING CABLES IN ONE FRAME.
By courtesy of the General Electric Co., Ltd.

staggered, the layout then being as shown in Fig. 57. Since the cables have lead sheaths, sharp bends should be avoided. If required, three or more cables may be used in a similar way. A double-pole switch with fuses and also a thermostat (if desired) are fitted to the frame. Although not essential, a thermostat gives more economical running, and enables the soil temperature to be maintained constant at any particular value to within two or three degrees Fahrenheit. Whether thermostats are used or not, time switches may be employed to eliminate risks of forgetting to switch the cables on and off when the heating is carried out for definite periods only, e.g. during the night. Time switches are used, also, when the supply undertaking is prepared to offer a special favourable tariff for certain " off-peak " hours, such as from 10 p.m. to 7 a.m. A charge of ½*d.* per unit for such a load may be considered as a reasonable possibility. Under these conditions the loading of the cables used should be rather higher than when the heating is carried on throughout the twenty-four hours. If the maximum temperature is attained just before switching off in the morning, the bed will retain its heat throughout the day if properly lagged.

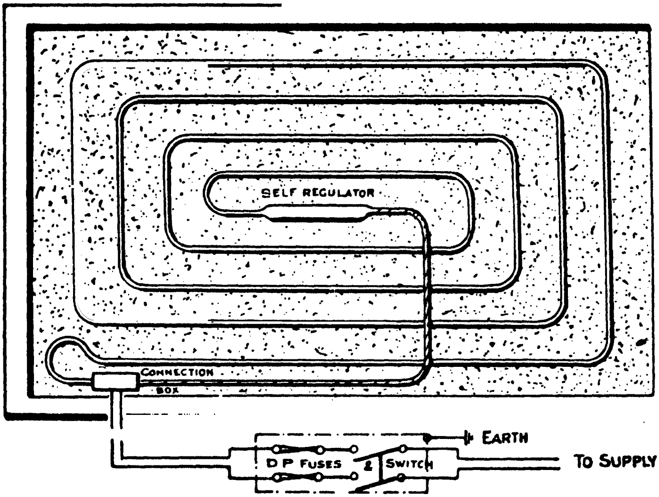

FIG. 58.—LAYOUT AND CONNECTIONS TO SELF-REGULATING SOIL-HEATING CABLE.
By courtesy of Siemens Bros. & Co., Ltd.

When used, thermostats should be placed at such points that their temperature is as nearly as possible the average temperature of the bed. They should not be placed near to the cables themselves, as this will cause the supply to be switched off before the whole of the bed has acquired the desired temperature. Messrs. Siemens Bros. have placed on the market a "self-regulating" cable in which the thermostatic device is included in the cable itself. This cable is supplied in unit lengths of 10 yards for temperatures of 50°, 60°, or 70° F., each 10-yard length being sufficient for an area of about 6 × 4 feet. One method of laying this cable suggested by the makers is shown in Fig. 58, while in Fig. 59 is shown a temperature chart and graph of the power consumption. The two important points to be noted are the uniform temperature of (in this case) 68° F. maintained at a depth of 9 inches below the surface, and also that for certain periods of the day, e.g. between 11 and 12 a.m., 2 and 3 p.m., and 5.45 and 8.30 p.m., the supply is completely cut off, while it is intermittent throughout the night, economical running being thus obtained.

When raising seeds in pots or in the case of cuttings, the pots or boxes are placed directly on the sand containing the cables, no soil being used.

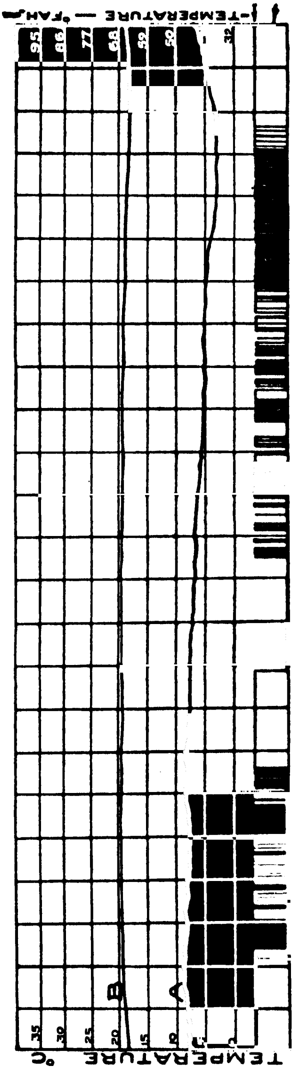

FIG. 59.—TEMPERATURE CHART OF SELF-REGULATING CABLE.

By courtesy of Siemens Bros. & Co., Ltd.

Soil-heating cables have been used, in some instances, in open ground, in which case the soil temperature is raised only some 10° F. above the normal ground temperature. If the crop to be heated consists of bulbs for early flowering, the acceleration in the flowering produced (from 3 to 6 weeks earlier than when unheated) will probably give a good margin of profit when the price of electricity is anything less than 1*d.* per unit.

Loading and Energy Consumption.—The process of soil heating may be divided into two parts: (*a*) raising the temperature of the soil to the required value, (*b*) maintaining this temperature over a period. The first part requires the supply of a definite amount of heat (or of its equivalent in electrical energy), and the second necessitates the provision of a quantity of heat (or electrical energy) per second, or per hour, to counterbalance the heat losses from the bed or frame which is being heated. We have seen, in an earlier chapter, that energy dissipated per unit of time represents power, so that the second part of the process—i.e. maintenance of the temperature—requires the supply of power (in watts), while the first part—the initial raising of the temperature—needs a quantity of energy which is best expressed in kilowatt-hours or units of electricity.

Considering these in order, we must first determine how much heat is required to raise the temperature of the soil initially. Now, the quantity of heat required in such a case is given by multiplying together the weight of the soil (in lb.) by the temperature rise required (in degrees Fahrenheit), and by a figure representing the "specific heat" of the soil, this being a fraction whose value varies with the type of soil and with its condition and moisture content. The heat is expressed in British Thermal Units (B.Th.U.).

Thus, for example, to raise by 10° F. the temperature of 100 lb. of soil whose specific heat is $\frac{1}{4}$ would require:

$$100 \times 10 \times \tfrac{1}{4} = 250 \text{ B.Th.U.}$$

Again, 1 unit of electrical energy is equivalent to 3,400 British Thermal Units, so that in this case $\frac{250}{3400}$ unit would be needed.

Now, the weight per cubic foot of soil varies from about 95 lb. to 150 lb., according to the type and moisture content. Thus, if we take average values of $\frac{1}{3}$ for the specific heat and 120 lb. per cubic foot for the density, we find that to raise the temperature 1° F. we require 40 B.Th.U. per cubic foot of soil, this being equivalent to $\frac{40}{3400}$ unit of electricity (kWh), i.e. $\frac{1}{85}$ kWh per cubic foot.

Turning now to the second part of the process, a steady temperature is reached when the heat lost by conduction through the soil per second is equal to that produced in the cables. It may be assumed, if the heating cables are laid only a few inches apart and if the bed is efficiently lagged to prevent the escape of heat round the sides and through the bottom of the bed, that the horizontal plane containing the cables is at an almost uniform temperature, and that all the heat produced passes from this plane upwards to the surface of the bed. The watts (equivalent to heat per second) required to maintain any given temperature difference between the cable layer and the upper surface depend upon :

(i) The depth of soil above the cables.
(ii) The surface area of the bed.
(iii) The thermal characteristics of the soil in the bed.

Again, for a given average soil temperature the temperature difference between the cable layer and upper surface will depend, of course, upon the air temperature above the bed, this being governed by the situation of the bed itself, or, if it is an open bed, upon the time of year and the climatic conditions.

It is perhaps best to express the power required in terms of watts per square foot of surface of the bed. For a depth of soil of 1 foot the watts per square foot required to maintain a given temperature difference between the cable layer and surface are given approximately by dividing this temperature difference (in degrees Fahrenheit) by 5. Thus, for a temperature difference of 30° F. 6 watts (i.e. $\frac{30}{5}$) per square foot of surface would be required. The figure by which the temperature difference is to be divided is proportional to the depth of soil ; thus, for a depth of only 6 inches, this figure would be $2\frac{1}{2}$ instead of 5 and the watts per square foot would be 12.

If the heating were continuous throughout the twenty-four hours, the consumption of electrical energy per twenty-four hours would be from 144 watt-hours (about $\frac{1}{7}$ unit) per square foot for soil 12 inches deep and 288 watt-hours ($\frac{2}{7}$ unit) for soil 6 inches deep, the temperature difference being 30° F. in each case.

In practice the temperature difference required will probably be less than 30° F., but will depend upon the crop to be raised. It is more usual, also, to install cables with a rather greater loading per square foot and to allow the heating to continue for only a few hours at a time. A loading of from 7 to 10 watts per square foot is suitable for nursery hotbeds.

The length of cable to be installed in any particular case depends, of course, upon the size of the bed as well as upon the required loading per square foot. Manufacturers vary somewhat as regards the standard lengths of cable supplied, 10, 40, and 50 yards and 25 and 100 feet being common. The watts per foot run of cable are usually about 5 to 6, so that, for example, to supply a frame 6 × 4 feet with 5 watts per square foot would need (say) a 25-foot length of cable with a total loading of 120 watts (approximately 5 watts per foot run).

It is impossible, in the space available here, to discuss the subject of soil heating more fully, but a large amount of useful information is available in the publications mentioned in the footnote.[1] General conclusions reached in these publications are that a reduction of as much as 30 per cent. in the growing time can be obtained, that for both nursery hotbeds and salad beds the use of such cables is economical if electricity costs 1*d.* per unit or less, and that early lettuces can be produced for a consumption of 1 unit per head.

Costs of equipment are approximately :

	£	*s.*	*d.*
Cable length :			
25 feet		10	0
50 yards	1	10	0
Self-regulating cable (10-yard length)	1	5	0
Thermostat	2	5	0
Switch, fuses, and wiring from £1 upwards, according to length of wiring required from nearest service point.			

Air Heating in Frames

Cables similar to those discussed above may be used to heat the air in frames. This is very useful in preventing damage to plants due to sudden sharp frosts and also to increase the average soil temperature for a given temperature difference between the cables and the surface of the soil.

The heating cables may be fastened round the sides of the frame just above the soil level or, if no soil is used, as when raising plants in pots, they may be laid on the floor of the frame. With cables running in air the advantage of the high heat capacity of the soil is lost, so that temperature variations due to changing climatic conditions are much more rapid than those in the soil. Thermostatic control of such air-heating equipment is thus essential if a uniform air temperature is to be maintained, and this should be combined with a higher loading (or wattage) of the cables so that sudden falls of temperature may be quickly corrected. The loading required is from about 15 watts per cubic foot of air space upwards to 40 or more watts per cubic foot according to the air temperature required. It is found that the air temperature rises to within a few degrees of its final steady value in about three hours.

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[1] *The Use of Electric Heating Cables for Hot-Beds*, by C. A. Cameron Brown, Institute for Research in Agricultural Engineering, Oxford (price 1*s*.). *Electricity in Horticulture*, by E. A. Beavis. Engineering supplement to the *Siemens Magazine*, August 1933 and May 1936. "Electricity in Horticulture," by F. E. Rowland, *Electrical Review*, December 6th, 1935. "Soil Heating by Electricity," by V. Sinclair, *Electrical Review*, March 8th, 1935.

Greenhouse Heating

The heating of greenhouses by electricity is applied most commonly in the case of cool houses in which the temperature is to be maintained, during the winter months, at a little above freezing point (say, 45° to 50° F.). For this purpose it is economical, (provided electricity is available at not more than 1*d*. per unit) and is very efficient, the temperature being controlled very easily, or, if thermostats are employed, automatically. When temperatures of 70° F. or more are required electric heating is, perhaps, rather more expensive than the non-electric methods, and it is somewhat doubtful as to whether it would be economical for the commercial grower unless the cost of electricity were very low (½*d*. per unit or less). In such cases, however, electric heaters may be used very successfully to supplement the main heating system by giving extra heat in very cold weather and at times when the main boiler is out of use. Again, in some districts exceptionally low tariffs are available for such heating purposes, especially if a time switch is installed to cut off the supply during the peak-load period (late afternoon), and the saving of labour and general convenience may make the installation of electric heaters worth while. For the amateur grower the cost of electric heating will not be excessive, and it is probable that the convenience alone will justify its adoption.

In addition to heating cables, already mentioned in connection with frames, tubular heaters and hot-water pipes supplied from a boiler having an electric immersion heater are used. Tubular heaters are most commonly employed, although the hot-water pipe system has the advantage of a greater heat capacity, so that if the supply is cut off at the peak-load period (under the conditions of a specially favourable electricity tariff) the house will cool down more slowly than when tubular heaters are used. Both systems may be thermostatically controlled so that the temperature may be maintained constant to within 2° or 3° F. with the minimum use of electricity.

Immersion heaters for the purpose may have loadings of from 500 to 2,000 watts (i.e. using ½ to 2 units per hour when in continuous operation) according to the size of the greenhouse.

The construction of tubular heaters for greenhouses is similar to that for ordinary domestic use as described in Chapter VII. The loading used is from 60 to 80 watts per foot run of tube.

The total loading required for any particular greenhouse depends upon the area of glass as well as upon the type and cubic capacity of the house, its position, and the temperature required As a rough approximation, for a temperature difference between inside and outside of about 15° F., the loading may be taken as 1½ watts per cubic foot for a house of 2,000 cubic feet capacity up to 3½ watts per cubic foot for a small house of about 300 cubic feet.

More precise estimates of the wattages required may be made by the use of the following table[1] which is used in conjunction with the formula—

Watts loading is given by the sum of :

Cubic capacity of house in cubic feet multiplied by x
Area of brick in square feet multiplied by y.
Area of glass in square feet multiplied by z.

TABLE XXV

REQUIRED TEMPERATURE WHEN 32° F. OUTSIDE

Constant	45° F.	50° F.	55° F.	60° F.	65° F.
x	0·2	0·3	0·4	0·5	0·6
y	1·5	2·0	2·5	3·0	3·5
z	4·0	5·5	7·0	8·5	10·0

Taking, for example, a greenhouse with a capacity of 3,000 cubic feet, having a total glass area of 800 square feet and brick area 250 square feet, to be maintained at an inside temperature of 45° F. with an outside temperature of freezing-point (32° F.) we have :

$$x = 0{\cdot}2, \quad y = 1{\cdot}5, \quad z = 4{\cdot}0.$$

$$\begin{aligned}\text{Watts loading} &= (3{,}000 \times 0{\cdot}2) + (250 \times 1{\cdot}5) + (800 \times 4{\cdot}0)\\ &= 600 + 375 + 3{,}200\\ &= 4{,}175 \text{ watts, or approximately } 4\tfrac{1}{4} \text{ kilowatts.}\end{aligned}$$

If tubular heaters having a loading of 70 watts per foot were used, about 60 feet of tubing would be required (say, four 15-foot lengths).

The initial cost of tubular heaters is about 3*s*. to 5*s*. per foot run, the former figure being for the longer lengths. In this example, therefore, the initial costs of the heaters with fixing brackets would be about £10. A thermostat for control purposes would cost about £2.

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[1] Given by The Wardle Engineering Co., Ltd., Old Trafford, Manchester.

As regards energy consumption, a greenhouse of the size mentioned in the above example would require between 300 and 500 units per month during the winter months if the internal temperature were to be maintained at 45° F. An approximate rule for the annual energy consumption is that the units used per annum are given by multiplying the number of kilowatts installed (i.e. 4¼ in the above example) by a figure which varies from about 1,000 in the case of an internal temperature of 45° F. to about 2,000 for a temperature of 60° F., although this rule may give rather too high figures if the installation wattage were calculated from the table and formula given above.

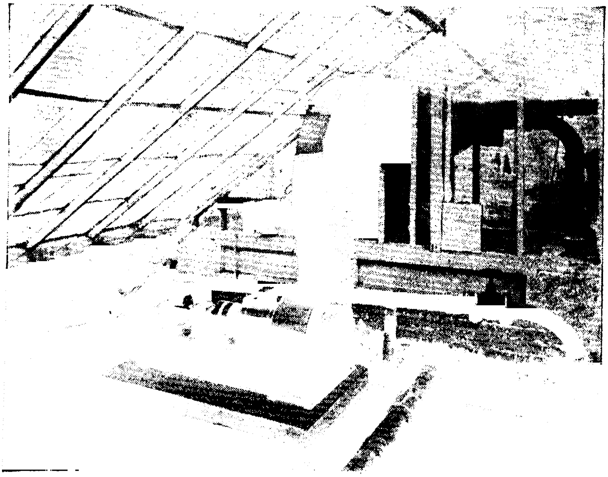

FIG. 60.—KEITH-BLACKMAN—B.T.-H. SYSTEM OF GREENHOUSE HEATING.
By courtesy of the British Thomson-Houston Co., Ltd.

Another application of electricity to greenhouse heating which is of a different nature from the above is the Keith-Blackman-B.T.-H. system. These heating units consist of an electrically driven fan and pump used in conjunction with existing hot-water heating systems. The fan gives greatly increased draught, so that a low grade (cheap) fuel can be used in the furnace, while the pump gives a positive water circulation which results in a higher and more uniform temperature throughout the greenhouse. This system is economical both in electricity and fuel costs, and enables the required temperature to be quickly obtained and easily maintained. An installation of this type is illustrated in Fig. 60.

Soil Sterilization

With the intensive cultivation practised in nursery gardens, sterilization of the soil to eradicate injurious bacteria, insect pests, and weeds becomes almost a necessity. In the past, three methods of sterilization have been used, namely—steaming, baking, and chemical treatment. All of these have their disadvantages: steaming, while economical for large-scale use, involves the installation of expensive plant, which requires considerable attention. A high-pressure boiler supplying steam at over 300° F. is necessary, although there is a tendency to overheat and so destroy useful bacteria. Baking by building a fire under the soil to be sterilized also involves the risk of overheating and rendering the soil deficient in moisture. Chemical treatment is less effective than heating, and there is a danger of harmful effects to plants or seeds sown after the treatment, owing to the presence of the chemicals used.

For sterilization by heating it is necessary to raise the temperature of the soil to between 200° and 212° F., this temperature being maintained for twenty to thirty minutes, when weed seeds and harmful bacteria are destroyed.

Although experimental work on electric sterilization was carried out by embedding electric heating elements in the soil, later developments have been along the lines of passing a current through the soil directly by means of two or more metal plates embedded in it.

A sterilizing equipment is now on the market[1] which uses alternating current (single-phase for small sizes and three-phase for the larger), the current being passed through the soil, which is placed in a special container for the purpose, by means of a system of electrodes. A temperature of 212° F. is reached, overheating being impossible, because at higher temperatures the soil becomes almost non-conducting. Very little moisture is lost during the process, and the energy consumption is from 25 to 40 units per ton of soil. The process of sterilization normally takes from two to three hours to complete.

Intensive Illumination

A considerable amount of experimental work has been done in various parts of the world to determine the effects of intensive illumination upon the growth of plants. There is no doubt that such illumination accelerates flowering in the case of flowering plants, and, if properly carried out so that the plants are not drawn up too quickly, strengthens the plant at the same time. Many flowering plants, such as narcissi, gloxinia, asters, cineraria, and begonias, have been treated successfully as well as cucumbers and strawberries.

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[1] Distributed by Messrs. G. H. Richards, Ltd., 234 Borough High Street, London, S.E.1.

Investigators have used various intensities of illumination successfully, and have found, as regards wavelength, that it is the red end of the spectrum which accelerates growth.

One of the commonest methods of applying this illumination has been by a 500- or 1,000-watt gas-filled lamp with a dispersive reflector, although a plant irradiator has recently been placed on the market[1] which is fitted with a red Osira flood-lighting lamp (470 watts). Whatever method is used, the lighting fitting can be made to illuminate a sufficiently large number of plants, so that the cost of electricity is a very small item in the production cost.

Since the whole question of intensive illumination appears to be still in the experimental stage rather than established commercial practice, the reader interested in such work is advised to study recent papers on the subject,[2] when he may decide for himself whether its use would be of value in his particular case.

Electroculture

This term has been applied especially to the use of electricity in increasing plant growth directly, i.e. by the application of an electric current or of a high voltage, as distinct from the use of electricity for heating or illuminating the plant. In almost every country in the world experiments upon such artificial stimulation of growth have been carried out, and, it may be said, by almost every imaginable method. An Electroculture Committee, appointed by the Ministry of Agriculture and Fisheries in 1918, has been responsible for the carrying out of research work in this country during every year since that date. The reports issued by this Committee indicate that although it may eventually be found possible to obtain consistent results by electrical stimulation, such consistency has not so far been achieved. Research work carried out at Rothamsted Experimental Station and elsewhere by various workers has shown that, in some instances, appreciable increases in crop can be obtained by suspending above the growing plants a network of wires charged to a high voltage (up to 100,000 volts). It has been claimed by some investigators that successful results have been obtained by passing a current of electricity through the soil in which the plants are growing or by collecting electricity from the atmosphere and subjecting the plants, in one way or another, to its influence. The difficulty is that in such work there are so many variable factors that it is almost impossible to repeat such results.

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[1] By the General Electric Co., Ltd.

[2] "Stimulating Plant Growth," by F. E. Rowland, *Electrical Review*, October 4th, 1935. "Irradiation of Plants with Neon Light," by J. W. M. Roodenburg and G. Zecher, *Philips Technical Review*, Vol. I, No. 7, July, 1936. (Published by N. V. Philips Gloeilampenfabrieken, Eindhoven, Holland.)

When attempting to repeat work carried out by another experimenter one is faced by the possibility—if not probability—of the various factors influencing growth, such as the chemical and bacteriological condition of the soil used, temperature, moisture, and climatic conditions generally, as well as the electric conditions, being different from those which gave the results which one is attempting to repeat. This renders it very difficult either to confirm or to deny that any given method of treatment yields beneficial results. Again, it is, in most cases, only possible to carry out one set of experiments in any particular line per annum, so that progress in the matter must necessarily be very slow. From the commercial point of view, therefore, one has no hesitation in saying that at present, and most probably for some years to come, electroculture must be regarded as merely an interesting field for research. In any case, the electricity supply authorities are not likely to be very interested in the subject from a profit-earning point of view since almost all of the methods so far invented have involved only negligible power consumptions.

Turning to the underlying theory upon which most of the research work has been based, it seems fairly generally accepted that any stimulation of growth which takes place is not due to any chemical change brought about by electricity either in the soil or the plant, but is intimately connected with an effect known as " electrical osmosis." If an electrical pressure, or voltage, is applied to the extremities of a system of capillary tubes which contain an ionic solution (represented in the case under consideration by the stem of a plant consisting of a number of tiny tubes carrying sap), a displacement of the liquid in the tubes is produced. The direction of this displacement depends upon the polarity of the applied voltage. From this phenomenon it would appear, therefore, that the rise of sap, and hence the growth of a plant, may be accelerated by the application of a suitable electrical pressure or voltage to its stem. This is the object of suspending highly charged electric conductors over the growing plants.

It should be pointed out that there exists in the atmosphere an electrical pressure (known as the "atmospheric potential") of from 40 to 140 volts per yard, this varying in magnitude at different times of the day. It has been stated that this atmospheric potential is an important factor in plant growth, so that artificial methods of augmenting it should, unless other disturbing influences are present, increase the growth. The reader may be interested to learn that the electric currents flowing to the plants when such methods are adopted are much less than one-millionth part of an ampere per plant.

PART III

ELECTRIFICATION FROM THE POINT OF VIEW OF THE ELECTRICAL ENGINEER

CHAPTER X

FARM WIRING

SATISFACTORY methods of wiring for ordinary domestic and business premises have been developed and are well known. It is unnecessary, therefore, to discuss here the wiring for such premises in rural districts, since the methods to be used differ very little, if at all, from those in urban districts. Farm wiring, by which is to be understood the wiring of the farm outbuildings, requires different treatment, and the matter is sufficiently important to warrant some discussion.

Now, while the farmer himself owns and is responsible for the internal wiring of his property, he cannot be expected to have sufficient electrical knowledge to enable him to differentiate between the various available methods and to choose that which is best suited to his requirements. In these circumstances he must rely very largely upon the good faith, skill, and workmanship of the firm carrying out the wiring, and it is in the interests of all concerned—farmer, wiring contractor, and supply undertaking—that the installation shall be entirely satisfactory. The main requirements are, of course, that the wiring shall be reasonably cheap, have a long and trouble-free life with the smallest possible maintenance requirements under conditions which are necessarily far from ideal, be well planned so that the various supply points and switches are conveniently placed and to render the system capable of being extended without undue cost or rearrangement, and, finally, that the risks of accident from fire or shock shall be reduced to a minimum. It is abundantly clear that compliance with these requirements necessitates considerable thought and skill on the part of the wiring contractor and a full realization of the factors militating against its achievement.

The farmer would be well advised to ensure that the firm carrying out the work is genuinely capable of doing it satisfactorily and to appreciate the fact that the first of the above requirements, namely, cheapness, is not necessarily the most important if one takes the long view. Now, low initial costs, which are made possible by shoddy material and poor workmanship, may prove very expensive in the long run when one considers the danger to life and property, as well as the inconvenience due to troubles in service which may be involved.

The whole situation might be improved by the introduction of enforceable regulations regarding consumers' wiring. The Institution of Electrical Engineers has issued at various times regulations which set a standard to be worked to in respect of wiring installations, but compliance with these on the part of the wiring contractor has not been legally necessary. Recent Electricity Supply Regulations issued by the Electricity Commissioners have been a step forward, since they give power to the supply authority to refuse to connect up an installation which is considered unsatisfactory. It is still possible, however, for a consumer to be connected to the supply when his installation is good enough to pass insulation and earth-conductivity tests imposed by the supply company but is of such a nature that it will prove unsatisfactory in service. The only real safeguard to the consumer is the employment of a reliable contracting firm.

Factors Necessitating Special Treatment

The following factors must be taken into account when planning a wiring system for farm buildings :

(1) *Dampness.*—It is impossible to avoid dampness in farm buildings, owing to the presence of animals (in cowsheds, stables, and the like), to the storage of crops and vegetable foodstuffs, and to the fact that, especially on old farms, the roofs are allowed to fall into disrepair to a greater extent than would be thought desirable in the case of the house. Even though suitable fittings are employed to exclude moisture as far as possible, these are not usually airtight, and moisture due to condensation is still present. The damp conditions render careful attention to insulation and earthing essential for safety.

(2) *Chemical Action.*—This may be due to the proximity of artificial manures and other stored goods, or to ammoniacal fumes from stables and cowsheds.

(3) *Extremes of Temperature.*—The wiring may have to be run under corrugated-iron roofs or in other situations where, especially in summer, the temperature is unduly high, while very low temperatures are met with in other places. The former is, of course, more important from the electrical point of view than the latter, since it reduces the carrying capacity of cables and may damage the insulation.

(4) *Insects and Vermin.*—Attacks upon the insulation from

insects and from rats and mice are more prevalent than in most other situations.

(5) *Mechanical Injury.*—Wiring is likely to receive rough treatment in farm buildings partly through accident, when heavy work with farm implements is being carried out, and partly through ignorance of the need for careful treatment of the electrical installation.

(6) *Long Runs of Cable.*—When a group of buildings is to be wired, the lengths of cable required are likely to be considerable owing to the often scattered layout, while long spans in the open, between buildings, may be unavoidable. This is, of course, an important point in connection with the costs of the installation.

Available Methods of Wiring

There are three general types of wiring which may be considered:

(*a*) Lead-covered cables.
(*b*) Conduit system.
(*c*) Tough-rubber-sheathed cables.

(*a*) The use of lead-covered cables may be thought, on first consideration, to be suitable for farm purposes, owing to the ease with which they can be fitted and to their cheapness as compared with other systems. In practice this system is, however, quite unsuitable, since the lead covering is not proof against mechanical injury, and the continuity of the earth circuit is very difficult, if not impossible, to maintain, owing to the action of ammoniacal fumes in corroding the lead. Incidentally, a lead covering seems to be particularly susceptible to attack by rats, especially if the cables lie in the way of their runs. Ordinary fastening clips, also, become corroded in damp situations.

(*b*) Conduit systems afford the best protection against mechanical injury, and are used in conjunction with V.I.R. cables. The conduit should, however, be galvanized steel, and should be screwed. The grip conduit system is inadmissible, since the joints are not watertight and the continuity of the earth circuit is soon destroyed under damp conditions. Heavy-gauge galvanized (or Z.I.R.) conduit is perhaps the only conduit system which will give the necessary mechanical protection together with a long life and a sustained earth continuity. In addition, such systems have the advantage that the wiring may be renewed easily and cheaply without dismantling the conduit.

The greatest disadvantage of screwed galvanized conduit of heavy gauge is its cost, although another disadvantage is that trouble may arise through condensation within the tubing.

Black-enamelled conduit of light gauge is cheaper, but is quite unsuitable for farm buildings, since it rusts very quickly and is corroded by chemical action. After a short time it is incapable of affording the cables any useful mechanical protection and the earth continuity is destroyed.

(*c*) Tough-rubber-sheathed cables (often referred to as cab-tyre sheathed, and including the various proprietary cables of the "-ite" class) are perhaps the most satisfactory for farm work, and are used together with insulating fittings to form an "all-insulated" system as opposed to the "earthed" systems (lead-covered and conduit) mentioned above. In this case mechanical protection is afforded by the tough-rubber sheath surrounding the insulated conductors. While perhaps inferior to conduit in this respect, the sheath will withstand considerable rough treatment, and it is also chemically inert. If exposed to bright light the tough rubber cracks in time, especially at sharp bends where it is stressed, although such cracking does not necessarily cause insulation troubles except in damp situations. For outdoor use this type of cable is covered with braiding impregnated with a weatherproof compound.

Cables of this type are easy to fix and form a cheaper system than conduit.

Most Suitable System

Both metal-sheathed and conduit systems fall so far short of the ideal as regards satisfactory and lasting earth continuity (unless constructed in such a manner that the expense is prohibitive), that there is little doubt that the all-insulated systems using tough-rubber-sheathed cables are best suited to farm purposes. As regards relative costs, Mr. C. A. Cameron Brown, in a paper on *Farm Wiring*,[1] which should be studied by all who are interested in this subject, gives the following prices for installations carried out in the best possible manner by highly skilled workmen :

	Per point.
Galvanized conduit (or Z.I.R.) screwed	30*s*.
Enamelled conduit :	
Screwed	26*s*.
Grip	23*s*.–25*s*.
Lead-covered :	
With iron boxes	23*s*.–25*s*.
With lighter fittings and wooden blocks for switches and ceiling roses	15*s*.
Tough-rubber-sheathed	23*s*.

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[1] Published by the Institute for Research in Agricultural Engineering, University of Oxford, Price 1*s*.

Apart from the possible trouble due to cracking when exposed to sunlight, which may be overcome by using braided cable, the only disadvantage of the all-insulated system is that it is somewhat difficult to obtain insulating fittings of high mechanical strength, bakelite and porcelain being the two commonest alternatives. This disadvantage may be overcome to a great

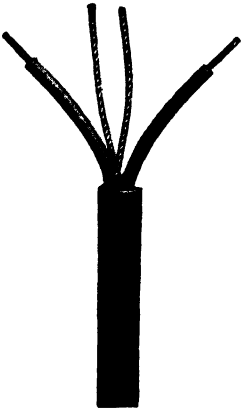

FIG. 61 (*a*) C.T.S. FLEXIBLE CABLE WITH CORD STRENGTHENERS.

By courtesy of Callender's Cable and Construction Co., Ltd.

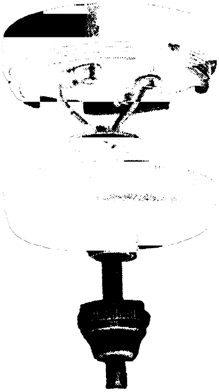

FIG. 61 (*b*).—C.T.S. 2-PLATE CEILING ROSE BOX.

By courtesy of Callender's Cable and Construction Co., Ltd.

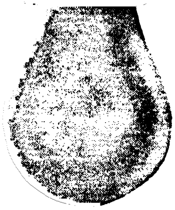

FIG. 61 (*c*).—SPECIAL JUNCTION BOX AND LAMPHOLDER.

By courtesy of Callender's Cable and Construction Co., Ltd.

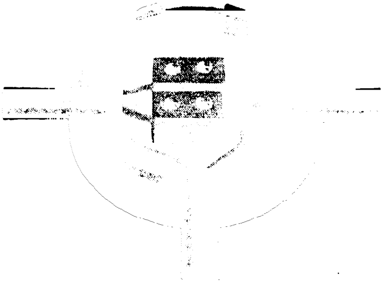

FIG. 61 (*d*).—JUNCTION BOX FOR "T" JOINT.

By courtesy of Callender's Cable and Construction Co., Ltd.

extent by planning the system so that these fittings are, as far as possible, placed in situations where mechanical injury is unlikely. The most suitable cable is 600-megohm grade Vicma. Flexible cables and suspended flexes should also be C.T.S., as ordinary silk-covered flex is unsuitable for farm use. T. C. Gilbert, in an article on " Wiring for Rural Installations," [1] discusses the most suitable system for farm buildings, and suggests that single-core C.T.S. cables should be used mounted on porcelain cleats, the conductor being solid and of hard-drawn copper, which is an advantage for the long spans which are often necessary between buildings.

Junction boxes for this system are usually of bakelite, and should be filled with plastic waterproof compound, although Mr. Gilbert suggests that no junction boxes should be used, the junctions being either soldered or mechanical "T" joints insulated with rubber or cloth tape and varnished over.

Switch boxes should have a gland at the bottom so that the conductors may form a loop before entering the switch. This loop allows moisture to drip off instead of entering the switch.

Another suggestion in this article is that, instead of the conventional method of grouping, local fuses should be used incorporated in the switch boxes, this being already the usual practice in the case of motors and heavier equipment.

Fig. 61 (*a*) shows the construction of a C.T.S. flexible cable with cord strengtheners. The cords pass throughout the length of the cable and afford a means of anchoring it at the ends without any mechanical strain falling on the cable itself. Fig. 61 (*b*) shows the construction of a C.T.S. 2-plate ceiling rose box, a fibre disc being used in this case to separate the two cores of the flexible cable. A special junction box with a lampholder is illustrated in Fig 61 (*c*), this fitting being useful where head room is limited. Illustration (*d*) is of a junction box for a "T" joint, a disc of cold plastic compound (Kalanoid) being pressed in the box before the joint is made. The box is completely filled with compound before the cover is screwed on, so that the joint is made moisture- and corrosion-proof. Since the compound remains plastic, a joint so made can be opened and remade at any time without difficulty.

Earthing

In view of the damp conditions prevailing in most farm buildings, the question of satisfactory earthing arrangements becomes a very important one. It is impossible to do more than review the matter briefly in the space available here, but a list of recent papers on the subject is given in the footnote[1] for the benefit of readers particularly interested.

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[1] *Electrical Review,* April 27th, 1934.

The situation is that if any insulation trouble occurs on the wiring system there arises the possibility of the potential of exposed metalwork being raised to a dangerous value, with the risk of serious shock to human beings and animals. In the case of animals, voltages above about 30 volts must be considered dangerous. There are various opinions as to the best method of ensuring against such potential rises, and these influence the method of wiring to be adopted.

In the all-earthed wiring systems, such as the lead-covered or conduit, the method of dealing with an insulation fault is to give a direct path to earth by means of the metal covering of the cable. This prevents a high potential being transmitted to exposed metalwork external to the wiring itself, because the current flowing to the sheath is sufficiently high to blow the fuse. The basis of such systems is, however, that the metal sheathing shall provide a continuous earth circuit of low resistance, and it is this question of continuity over a period of time under arduous conditions which forms the weak link in the chain of argument in favour of such systems. As has already been pointed out, it is difficult to ensure such continuity, particularly with the lead-covered system, and an earthed system with a faulty earth circuit becomes more dangerous than an all-insulated system. If a break occurs in the earth circuit it is probable that a large section of the sheathing will be raised to a dangerous potential above earth, and accidental contact with this is quite possible.

The supply company earths one side of a single-phase supply or the neutral of a three-phase supply at the substation. It has been advocated that multiple earthing of the neutral will solve earthing difficulties on rural systems by giving a low-resistance earth at each installation. Up to the present, however, the practice has been discouraged, and the consent of the Electricity Commissioners is required before multiple earthing can be adopted in any district.

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[1] "A Review of Recent Developments in Rural Electrification," by D. Ross, *Journal I.E.E.*, vol. 77, p. 797. "The Resistance of Earth Electrodes" (E.R.A. Report), by P. D. Morgan and H. G. Taylor, *Journal I.E.E.*, vol. 72, p. 515. "The Earthing of Low-voltage Installations," *Electrical Review*, November 29th, 1935. "Earth Leakage Trips," by T. C. Gilbert, *Electrical Review*, September 27th, 1935. "Multiple Earthing," by T. C. Gilbert, *Electrical Review*, December 27th, 1935. "A Neutral Relay," by A. G. Bullen, *Electrical Review*, September 20th, 1935. "Earth Leakage Protection," by J. S. Pickles and D. Ross, *Electrical Review*, December 7th, 1934. "New Methods in Agriculture," by T. C. Gilbert, *Electrical Review*, July 26th, 1935. "Farm Wiring and Earth Leakage," by C. A. Cameron Brown in *Report on the Use of Electricity in Agriculture*, Rothamsted Experimental Station, 1936. *Artificial Earthing for Electrical Installations*, by T. C. Gilbert, Benn Bros. "An Investigation of Earthing Resistances," by P. J. Higgs, *Journal I.E.E.*, vol. 68, p. 736.

Where a water supply exists, a low-resistance earth may be obtained by connection to water pipes, but in many instances in rural districts no such supply is available or is sufficiently near to the earthing point to be useful. It has been found very difficult to obtain earths having a resistance of less than (say) 8 or 10 ohms, and earth resistances of much greater values than this are more than likely. In this connection the I.E.E. paper by Morgan and Taylor already mentioned gives valuable information. To obtain a low-resistance earth, these authors recommend the use of 1-inch diameter pipes (or ¾-inch diameter rods) driven 6 feet into the ground, and state that "such an electrode has a resistance of rather less than 50 ohms in soil having a resistivity of 10,000 ohms per cm. cube. Two in parallel, if spaced not less than 6 to 8 feet apart, have a resistance of about 60 per cent. of one, and three have a resistance of about 45 per cent. Probably the resistance of any number of pipes in parallel and 6 feet apart, arranged in a straight line or circle, is not more than 1·5 times the value calculated from the formula for resistances in parallel." Treatment of the ground with common salt is recommended to reduce the earth resistance.

The conclusion to be drawn from the above remarks upon earthing in connection with all-earthed systems is that, on the whole, there is insufficient security against dangerous potential rises, and that provided suitable earthing arrangements can be made for the exposed metal parts, such as switch boxes and the frames of machines, the all-insulated system is likely to prove the safest.

With this system, then, the main requirement is the provision of suitable earthing devices for the metal parts of the equipment supplied, and in this connection earth-leakage trips, which operate on currents of about 30 milliamps., are likely to be the solution. They have been developed within recent years and have not yet been generally adopted, but it is difficult to find any alternative method of earthing which will prove so satisfactory. The tenth edition of the *Regulations for the Electrical Equipment of Buildings*, issued recently by the Institution of Electrical Engineers, suggests the use of earth-leakage trips to supplement the earthing whenever it is impossible to obtain an earth resistance of 1 ohm

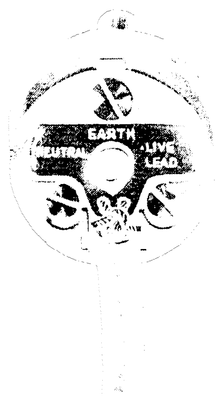

FIG. 62.—3-PIN PLUG.
By courtesy of Callender's Cable and Construction Co., Ltd.

or less. Such a low earth resistance is usually very difficult to obtain in rural work.

The earth-leakage trip consists of a coil, having a resistance of several hundred ohms, incorporated in the main switch to the apparatus, one end of the coil being connected to the metalwork and the other to an earthing rod or plate. This coil is energized by the potential arising on the metalwork due to leakage, and brings out the switch when the leakage current rises to about 30 milliamps. Thus, if the resistance of the earth itself (at the earthing rod) is as much as 500 ohms, and the coil itself is another 500 ohms, a voltage above earth of 30 volts will produce the necessary current (30 milliamps.) to cause the trip to operate. With the employment of this device, therefore, a low-resistance earth is not relied upon, and the resistance may be as much as several hundred ohms without preventing its operation.

The cost of these leakage trips has been held up as a disadvantage, but they are now available at prices of from 11*s.*

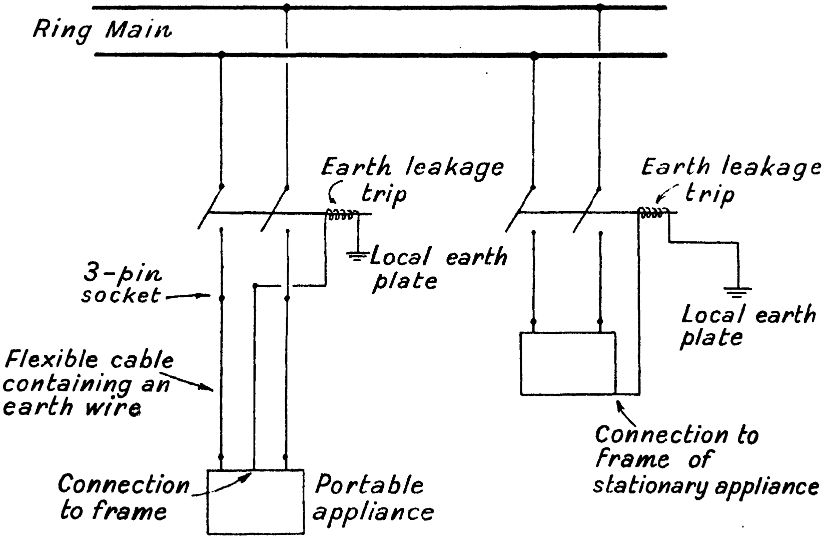

FIG. 63.—RING MAIN WITH CONNECTED APPARATUS.

to £2, and cannot be regarded as expensive when the protection afforded by them is considered. Moreover, the cost of the device is offset by the saving brought about by the fact that a separate earth conductor, often used to obtain a low-resistance earth connection, becomes unnecessary. The device may be tested quite easily, so that there should be no difficulty in ensuring that earth protection is always existent. When a metal-covered or conduit system is used, an earth-leakage trip may be incorporated, the connection being from the sheathing, through the trip, to earth. A disadvantage of this is, however, that the whole system is disconnected from the supply as a result of an earth fault on one piece of apparatus.

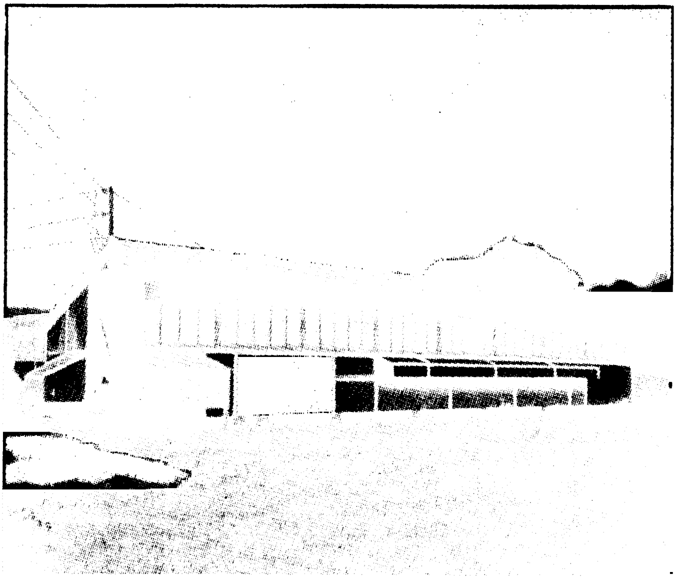

FIG. 64.—OVERHEAD CONSTRUCTION.
By courtesy of Callender's Cable and Construction Co., Ltd.

For portable appliances the flexible cable should contain a separate earth wire, which can be connected, through a 3-pin socket, to the leakage trip and the supply. The internal arrangement of a 3-pin plug for this purpose is shown in Fig. 62, the flexible cable in this case being C.T.S. flexible with cord strengtheners, the ends of the cords being tied through the shield as shown.

A ring main is commonly employed for farm buildings, and the connections of apparatus to this when earth-leakage trips are employed are as shown in Fig. 63.

Connections from one building to another may be made by an overhead line, using either light wooden poles or, where possible, brackets attached to the buildings. Where braided C.T.S. cable is used for overhead work a supporting wire is necessary, it being very undesirable that such cable should be supported only by its own tension. The height above ground should be from 17 to 20 feet, so that accidental contact with loaded farm carts passing underneath should be avoided. Examples of suitable overhead construction are shown in Figs. 64 and 65.

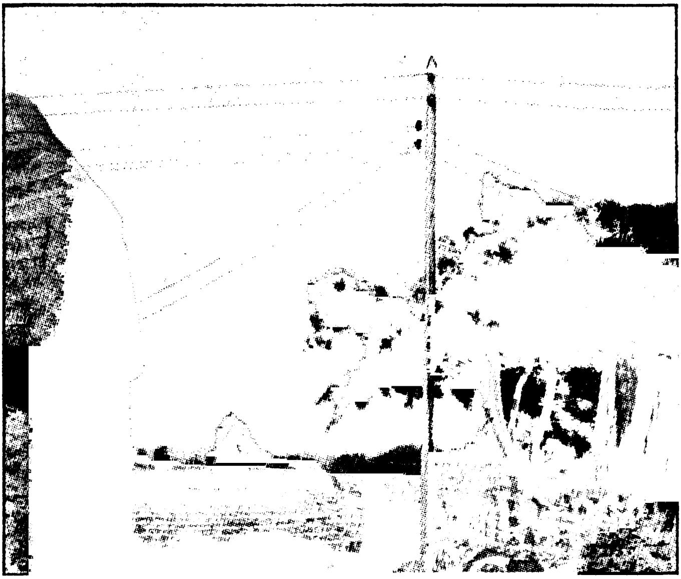

FIG. 65.—OVERHEAD CONSTRUCTION.
By courtesy of Callender's Cable and Construction Co., Ltd.

With regard to the cross-section of cable required, the two requirements to be borne in mind are, that neither the heating nor the voltage drop in the cables shall be excessive. The current likely to be taken from the circuit being known, the size of cable required can easily be obtained from tables giving current-carrying capacities of the various sizes. Voltage drop is important, and in this connection it should be remembered that the total length of cable (reckoning both lead and return) for a drop of 1 volt is from 30 to 60 feet according to the size used, exact figures again being obtainable from tables. It is important that the above considerations should not be overlooked when installing a wiring system with a view to possible extensions, since the comparatively long runs in and between farm buildings may be responsible for a serious voltage drop if too small a size of cable is used.

A large number of protected type plugs and sockets for the connection of small power devices have been developed. Fig. 66 illustrates the Easigo plug and socket.[1] The socket has an earth terminal, and earth contact through the plug is made by a springy scraping connection. The plug is of the 3-pin type and the arrangement is weatherproof. The flexible cable has flexible metal guards and the plugs may be fitted with 1-amp. or 4-amp. fuses without loss of interchangeability. This type of plug may, of course, be used in conjunction with an earth-leakage trip switch.

Where no plug socket is available and where no earth connection is essential, a device of low wattage may be connected to the supply through a two-way adapter fitted to a lampholder.

For inspection lamps, the use of a small portable transformer, stepping down to 25 or 12 volts for the lamp, is perhaps the best method of ensuring safety.

Financial Aspect

Until more prosperous conditions obtain in the farming industry, and, in addition, the value of an electricity supply is more fully appreciated, the initial costs of installation may prove a stumbling-block in the way of progress unless a satisfactory way of meeting these costs can be found.

In urban districts particularly, assisted wiring schemes, introduced either by the supply authority or by some external financial organization, have proved the means of obtaining a large number of consumers. It is less certain, however, that such schemes are likely to be as successful in the case of farms, for which the installation is likely to be more expensive and the costs of repayment, when added to the necessarily higher electricity charges, may place electrification in an unfavourable light.

Where assisted wiring has been adopted, the capital costs of the installation have been recovered either by a number of fixed quarterly charges or by the use of prepayment meters, which are calibrated so that the consumer pays an additional charge per unit on account of the hire-purchase of the installation. This is continued until a sufficient number of units, at the increased charge, have been used for the whole capital cost to be met. Collection of such charges by prepayment meters is probably best in the case of small consumers.

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[1] Manufactured by A. Reyrolle & Co., Ltd.

The situation is complicated, also, by the fact that many farms are occupied by tenants, who naturally hesitate to undertake the expense of installing electricity on property which is not their own.

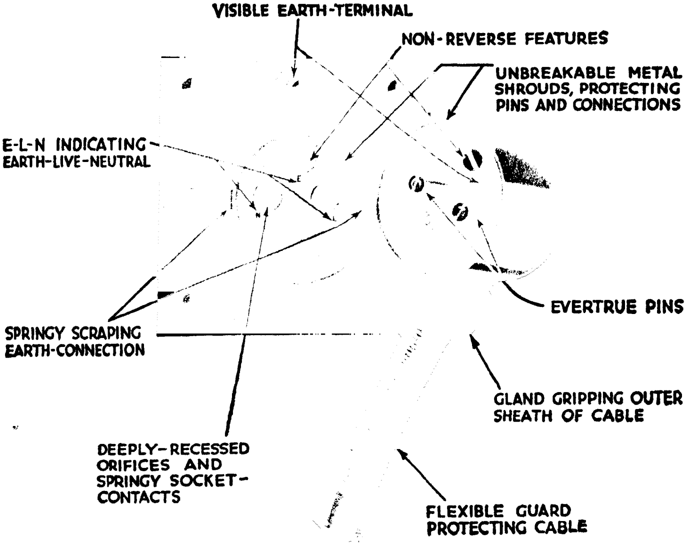
VISIBLE EARTH-TERMINAL
NON-REVERSE FEATURES
UNBREAKABLE METAL SHROUDS, PROTECTING PINS AND CONNECTIONS
E-L-N INDICATING EARTH-LIVE-NEUTRAL
EVERTRUE PINS
SPRINGY SCRAPING EARTH-CONNECTION
GLAND GRIPPING OUTER SHEATH OF CABLE
DEEPLY-RECESSED ORIFICES AND SPRINGY SOCKET-CONTACTS
FLEXIBLE GUARD PROTECTING CABLE

FIG. 66.—EASIGO PLUG AND SOCKET.

By courtesy of A. Reyrolle & Co., Ltd.

In many cases, however, landlords are prepared to undertake improvements to farms, such as, for example, the alterations necessary on dairy farms to satisfy the requirements for high-grade milk production, on the understanding that a somewhat increased rent shall be charged by way of interest on the capital invested in the improvements. There seems no reason why a similar arrangement should not be made in connection with electric wiring, provided the landlord and tenant can be persuaded as to the improvement which would be brought about by such an installation.

It is also possible, subject to the approval of the Ministry of

Agriculture and Fisheries, to obtain loans for the improvement of farms from the Lands Improvement Company.[1] The negotiation of loans for electric light and power installations forms one branch of the company's activities. Such a loan, which is secured on the rental value of the property, may be repaid by instalments spread over a period not exceeding twenty years, the rate of interest at present being 3¼ per cent. (net). Investigation of title or deposit of deeds is not required, but the Ministry of Agriculture and Fisheries must be satisfied that such work as is proposed will be for the permanent improvement of the property. An interesting point is that it is stated, in the "Instructions to Applicants," that "the cable from the supply company's lines can form an item for inclusion in the loan applied for."

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[1] 58 Victoria Street, Westminster, London, S.W.1.

CHAPTER XI

THE PROBLEM OF ECONOMIC SUPPLY TO RURAL AREAS

In the first place, it will be generally admitted by most electrical engineers that the question of rural electrification is one which cannot lightly be put aside as an economic impossibility in spite of the many serious difficulties with which a supply company may be faced when studying the financial aspects of the problem. The National Grid Scheme was developed with a view to making an electricity supply available in rural districts, and there can be no doubt that the inhabitants of these districts have a right to such a supply, while the benefits of electricity at a reasonably low price can easily be shown to be even greater than is the case in urban districts. At the same time, while saturation-point has certainly not yet been reached in the densely populated areas, it is becoming increasingly necessary to find fresh fields for expansion if the rate of development of the past few years is to be maintained. Rural electrification, then, must and will be proceeded with, the important question being how this can be done economically.

It is generally recognized that the main difficulties are those associated with distribution costs in the case of areas having a population density of 150 or less per square mile in view of the comparatively low consumptions and poor load factors which appear probable, especially when the districts concerned possess few industrial concerns likely to help by taking large amounts of power. It is possible to work out a scheme which would be economical for a large district including such industrial loads, but in practice such a division of territory is impossible under existing conditions in the supply industry. The recommendations of the McGowan Committee on Electricity Distribution, whose recently published report is discussed later in this chapter, if carried out will do much to improve the present state of affairs, but for the present, at least, progress in rural districts must depend very largely upon the initiative of the supply engineer and upon his courage in carrying out a programme of electrification which may take some time and much intensive development work before it becomes financially successful.

In Chapters III and IV an attempt was made to arrive at figures for the probable power demands and energy consumptions in different districts and by various classes of consumers. Some information with regard to costs of supply, together with an account of progress already made in rural electrification, was also given. It is impossible to lay down simple rules for the accomplishment of economic supply in any particular district. Messrs. Dickinson and Grimmitt, in a paper already referred to,[1] have given much valuable information on the design of a rural distribution system as applied to an imaginary area under the average conditions obtaining in Great Britain, and such a method is probably the best conceivable one in attempting to formulate a general scheme. Actual conditions in different supply areas must, however, vary to such an extent that the engineer in charge is the best judge as to the procedure most suited to his own district. As regards the purely technical aspects of the problem, such as methods of obtaining satisfactory voltage regulation and the most suitable designs for transformers, switchgear, protective devices, and overhead lines, much has already been published on the subject in textbooks on transmission and distribution and in the technical Press. The discussion of such matters, which would be very lengthy, cannot be undertaken in the present volume, and, in view of the existing publications, would be rather unnecessary. A list of recent papers on certain aspects which are particularly important in rural work is, however, given in the footnote [2] below, and, although not by any means exhaustive, may be found useful by readers interested in the subject.

Economical Costs per Unit for Various Purposes

One of the most important considerations, when discussing the building-up of a satisfactory rural load, is the price at which electricity must be available in order that it may be applied economically to various farming and other rural processes. It is obviously against the interests of both the supply authority and the consumer to give a supply for a particular purpose at a price which will prove to be uneconomical to the consumer. Even though the consumer, through ignorance of the exact costs of electrical operation, may be persuaded to take a supply, it must be only a matter of time before he finds that electrical methods are proving too expensive, and the dissatisfaction resulting is likely to be more harmful to electrification generally than if no supply had been given.

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[1] *Journal I.E.E.*, vol. 70, p. 189.

[2] "Design Data in Rural Distribution Lines," by R. Dean, *Journal I.E.E.*, vol. 77, p. 749. "A Review of Recent Developments in Rural Electrification," by D. Ross, *Journal I.E.E.*, vol. 77, p. 797. "The Design of a Distribution System in a Rural Area," by E. W. Dickinson and H. W. Grimmitt, *Journal I.E.E.*, vol. 70, p. 189. "Rural Cable Systems," by P. V. Hunter and H. J. Allcock, *The Electrical Review*, May 29th, 1936. "Switchgear in Rural Areas," by A. Upton, *The Electrical Review*, January 18th, 1935. "Transformer Developments, with Particular Reference to Distribution Schemes," by R. M. Charley, *Electrical Industries*, November 8th, 1933. "The Grid and Planning Distribution for the Future," by W. Fennell, *Electrical Industries*, November 8th, 1933. "Pole-mounting Transformers," by A. Middleton Perry, *The Electrical Review*, May 11th, 1934.

In attempting to give exact prices for economical working, the difficulty arises that most rural consumers take a mixed load, including a certain proportion for lighting purposes, the economical price for which may be far greater than that for the major part of their load. The lighting load only is, however, of comparatively small financial importance to both the consumer and supply authority, and it is with regard to the heavier loads that both parties must be satisfied as to economy. It should be pointed out that in this discussion the economical price per unit from the consumer's point of view is taken as that at which electricity will compete on favourable terms with any alternative method of carrying out the work. From the supply point of view the economical price must be that for which a reasonable return on the capital expended will be obtained, not immediately, but within (say) two or three years after the date of connection to the supply, a reasonable amount of load-building activity being assumed on the part of the supply undertaking.

It is clear that the charge made for electricity must be fixed with both sides of the question in mind if electrification is to proceed satisfactorily. Now, the lowest economical price at which a supply can be given depends upon a number of variable factors, such as the density of population and its distribution as affecting the lengths of lines required, the skill of the supply engineer in designing the distribution system to give the lowest possible capital costs consistent with satisfactory service, and so on. On the other hand, the highest economical price from the consumer's point of view is more or less the same in all rural districts, the costs of the alternative sources of power, heat, and light, namely, manual labour, horse labour, oil, and coal, varying little in different parts of the country.

It is possible, therefore, to lay down certain economical prices of electricity for different rural purposes which are of fairly general application, and these may serve to indicate to the supply engineer the price conditions imposed upon him by any particular load. Modification of tariffs to suit many different types of consumer is not, of course, a practical possibility, since, apart from the labour involved, it would lead to undesirable comparisons of charges amongst the various consumers in the same district. At the same time, a little more flexibility appears desirable, and it is clear that to bear in mind the price requirements of the individual consumer is a more satisfactory method of load-building than merely to lay down a general tariff which is profitable from the supply point of view. When, for example, a farmer buys ordinary farm commodities, such as artificial manures or foodstuffs, he is in a position to judge for himself as to the economy of his purchase, and, moreover, if he finds that a particular commodity does not prove profitable, he may cut his losses on the consignment and buy no more. In the case of electricity, however, the farmer is not usually able to judge for himself with the same facility whether a supply with a certain tariff will be profitable or not ; nor, having accepted a supply, is he able to discontinue its use without the loss of an appreciable amount of capital on account of his installation. To a great extent, therefore, the farmer is at the mercy of the supply engineer as regards the economy of a supply, and it behoves the latter to satisfy himself that electricity at the rate offered to the consumer will be profitable. As a general guide on this point, the following list of price requirements for economical use may be of interest :

TABLE XXVI

Load.	Price per unit for the use of electricity to be economical.
Lighting and small domestic appliances. Groomers and clippers. Plucking machines and small power applications to poultry farming, such as egg-washing and grading machines. Small motors for dairy work	6*d*. or less.
Motor-driven barn machinery and milking machines . . .	2*d*. or less.
Domestic heating, cookers and cooking appliances, refrigerators, and water heaters. Soil heating. Poultry-farming load, including incubators, brooders, etc.	1*d*. or less.
Sterilizing and hot water for dairies, crop drying. Tubular heating for buildings	¾*d*. or less.
Greenhouse heating with thermostatic control	½*d*. or less.

The prices quoted above take into account, where applicable, the fact that maintenance, depreciation, and interest charges are usually less for electrically operated appliances than for those operated by alternative methods. In such estimates it is impossible to allow for the saving of time which may be brought about, and this, together with the general convenience and other advantages of electricity which are difficult to assess in monetary terms, may be advanced in favour of electricity in cases where the lowest tariff which can be offered to a consumer corresponds with or is slightly above the upper limit for economical use.

In addition to the above-mentioned prices, which may be taken as those which a consumer can economically pay for any particular type of load, it is important to know what are the approximate annual consumptions of such loads. The revenue obtainable by the supply authority depends upon two factors —price per unit and annual consumption. With the prospect of a satisfactory revenue due to a high consumption, the supplier can offer a lower tariff than would be possible in the case of a small load, so that probable consumptions must influence the question to a considerable extent. Incidentally, it has been shown by several authorities that a reduced tariff usually leads to an increased revenue, owing to the encouragement which it affords to increase the consumption. The increase in the number of units sold more than counterbalances the reduced charge per unit.

With the object of showing the relative values to the supply company of the different types of load mentioned previously, and so placing them, as it were, in the correct perspective, the chart shown in Fig. 67 has been drawn up. The reader will appreciate that, in arriving at figures for probable annual consumptions, only a general average can be taken. Several of the loads mentioned must, of course, vary as regards consumption according to the size of farm, horticultural holding, or equipment considered. In order to avoid excessive cramping of the scale for the majority of the loads considered, the few with a high economical price per unit or a high annual consumption have been placed in positions which are not to scale. The most valuable load to the supply company appears to be that for milking machines, the annual consumption being fairly high, while the price per unit which can economically be paid is also considerable.

On this chart has also been drawn a curve plotted from a formula given by Dickinson and Grimmitt and already referred to in Chapter III. This is for the price per unit as related to the annual consumption per consumer, and is as follows :

$$\text{Cost per unit (pence)} = \frac{1{,}140}{\text{units sold per consumer}} + 0{\cdot}73.$$

It was derived from the returns of 221 authorized undertakings

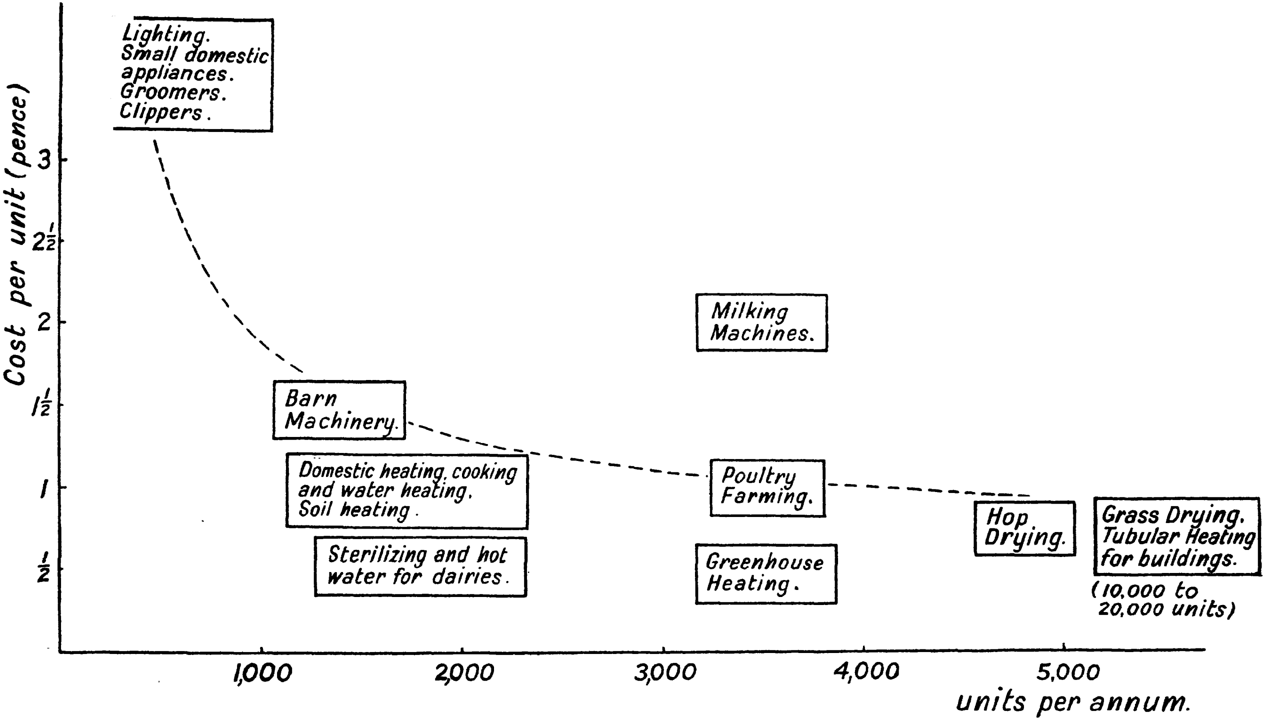

FIG. 67.—SHOWING RELATIVE VALUES OF DIFFERENT TYPES OF LOAD.

in Great Britain, and relates to their operations within rural areas. Now, while the formula was derived from the figures for "total units sold," "total revenue," and "total consumers" in the rural area concerned, and is, therefore, general rather than individual in character, it is not unreasonable to suppose that for a consumption of (say) P units per annum a satisfactory revenue is that obtained by multiplying P by the corresponding price per unit taken from the curve.

Let us apply this to the consideration of the case of a particular consumer. Suppose a rural consumer requires 500 units per annum for lighting and small-power domestic purposes, and could utilize economically 3,000 units per annum provided the price per unit for this 3,000 units were $\frac{3}{4}$*d*. Then, from the curve, it appears that for a supply of 3,500 units per annum the economic price from the supply point of view is 1·05*d*. per unit, or, in other words, the revenue which must be received is (3,500 × 1·05)*d*., or 3,680*d*. Reckoning 3,000 units at $\frac{3}{4}$*d*., we have a revenue of 2,250*d*., leaving a deficit of 1,430*d*. Now, if this were made up by a fixed annual charge (or the equivalent four quarterly charges) it would be equivalent to charging 2·86*d*. (i.e. $\frac{1430}{500}$)*d*., per unit for the lighting and domestic load, and this is within the economic price for such purposes. This illustrates the advantage of a two-part tariff, and, at the same time, shows that the requirements of rural consumers, as indicated in the chart, are not incompatible with those for economic supply.

Costs of Supply and Revenue Obtainable

Regarding the power requirements on farms and in rural districts and the annual consumption on different bases—per consumer, per head of population, per square mile, or per mile of route—much has been said already in Chapter III, where some facts relating to supply costs and revenue were also given. A brief summary of these facts, together with other data connected with costs and revenue, is given below. The figures stated are derived as a result of the intercomparison of statements and accounts given byvarious supply engineers and authorities, these applying, in some cases, to actual working and in others to estimations based upon past experience. They must be considered as referring to a system which is carefully planned initially to take into account probable developments in the supply area, the transmission and distribution costs being reduced as far as is consistent with safety and reliability of the supply. A tariff of such a nature as to encourage the extended use of electricity and adequate publicity for load development are also assumed. It will be realized that any new scheme of rural electrification cannot be expected to be placed on a profit-earning basis immediately, the period required usually being from 6 to 10 years from the date of commencement of supply.

Summary.	Average units per annum.
Annual consumption :	
Per head of population	100
Per consumer (excluding large power consumers)	1,200
Per square mile	30,000
Per mile of route	20,000
Taking the consumption per consumer in more detail, we have :	
Residences with cooking, lighting, and small-power domestic uses	3,500
Residences without cooking or water heating	500
Farms (medium size) with cooking in farm-house	8,000
Farms without cooking or water heating	5,000
Farm consumption per acre	50
Average revenue per consumer	£10
Capital expenditure required per consumer for transmission and distribution purposes	£35

(The capital outlay per consumer depends, of course, upon the development of the scheme as regards the number of connections made to the supply, since the distribution costs per mile of route are much less than proportional to the number of consumers connected. The figure given is for the case of a line fully loaded.)

Units sold per £1 of distribution capital expended	40
Load factor	25 per cent.
Total cost per unit sold, including costs of bulk supply, distribution costs, capital charges, and management	1¼*d.*

The total revenue should be at least 20 per cent. of the total distribution capital. This condition is fulfilled in the case of the figures for revenue per consumer (£10) and capital expended per consumer (£35) given above. For such a 20 per cent. return the 40 units sold per £1 of capital should thus yield a revenue of 4*s.* (i.e. 20 per cent. of £1), or 1⅕*d.* per unit. It is clear that the average price per unit must actually be rather greater than this to yield a profit after covering the cost per unit of 1¼*d.* stated above.

Looking at the question from the point of view of a two-part tariff, the fixed charges should produce about 15 per cent. of the total capital expenditure on the rural distribution scheme in order to cover capital and other fixed costs, while, in addition, 1*d.* per unit will cover the energy charge (which averages about 0·65*d.* for a bulk supply), and will leave sufficient to cover the remaining costs associated with the supply.

A recent paper by Mr. J. A. Sumner on " Private Plants and

Public Supply Tariffs"[1] gives much interesting information regarding the costs of supply in rural and semi-rural areas. The paper contains details of costs for two areas forming part of an existing electrification scheme. Details of these areas are as follows :

(i) Semi-rural area :	
Area	103 square miles.
Density of population	540 per square mile.
(ii) Rural area :	
Area	354 square miles.
Density of population	110 per square mile.

Taking the two areas together, the density of population is 210 per square mile, which must be considered fairly low.

It is pointed out that it is not economically possible to supply all the premises situated in a rural area, the economic limit being reached when about 70 per cent. are supplied. The ratios of $\frac{\text{dwellings on route of mains}}{\text{total dwellings in area}}$ are given as 65 per cent. and 62 per cent respectively for the two areas, while the corresponding expenditures of capital for distribution are £27 and £24 per dwelling on the route of the mains. These figures are in fair agreement with that of £35 already stated for the distribution capital required per consumer.

In a most interesting comparison of rural and urban undertakings it is stated that the distinction between these " is not to be found in the financial results which are ultimately achieved " but that the real difference is that in the case of a rural undertaking heavy and temporarily unremunerative expenditure has to be incurred in the initial stages of development " to provide an almost complete transmission scheme before being able to connect sufficient consumers to ensure an adequate return on capital." The urban undertaking, on the other hand, needs to expend a much smaller amount on mains to secure a large number of consumers.

A point which has already been made in the preceding pages regarding the increased revenue to be obtained, through increased consumption, as a result of reduction of tariffs is emphasized in this paper, and it is shown, from analysis of actual costs and revenues, that the tariffs for a rural area need not be very different from those for an urban area, although in the initial stages of rural development a higher tariff is almost unavoidable if the financial deficits in the first few years are to be kept within reasonable limits. It does, indeed, appear that the consumers connected at the outset of such a scheme must to some extent bear the brunt of the initial heavy development costs, but it is in the interests neither of the consumers nor the supply undertaking that high tariffs should be continued for a longer period than is absolutely necessary. A gradually reduced tariff should assist materially in building up a satisfactory load, and when this procedure is backed up by adequate publicity and other load-building methods, such as canvassing and demonstrations, there is no reason to doubt that financial equilibrium can be attained within a very few years. An interesting conclusion is reached in this paper with regard to annual costs exclusive of the cost of energy. This is, that after about the fifth year, these amount to about 12 per cent. of the capital expenditure on the distribution scheme.

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[1] *Journal I.E.E.*, vol. 77, p. 310.

The actual total costs of supply, including charges for bulk supply of energy, are given as:

For semi-rural area alone (in the seventh year):	
H.T. supplies	£3·87 per kW + 0·39*d.* per unit.
L.T. supplies	£11·6 per kW + 0·39*d.* per unit.
Average cost per unit sold	0·88*d.*
For whole area (in the tenth year):	
H.T. supplies	£3·83 per kW + 0·37*d.* per unit.
L.T. supplies	£8·92 per kW + 0·37*d.* per unit.
Average cost per unit sold	1·08*d.*

The layout of the system follows the most usual practice, namely:

Main transmission at 33,000 volts.

Secondary transmission at 11,000 volts, 3-phase, the spurs or extensions from the ring mains being also 3-phase, as it was considered that "single-phase extensions are uneconomical and unsuitable."

Low-tension distribution at 400/230 volts by overhead lines (chiefly). Some single-phase overhead distribution lines are used, but provision is made for conversion to 3-phase if and when necessary.

The total length of lines and cables for the whole system (in the seventh year) is 485 miles, of which 8 per cent. is 33,000-volt, 61·5 per cent. is 11,000-volt, and 30·5 per cent. low-tension. In addition, there is 70 miles of services. Exclusive of the latter, the percentage of overhead lines is 91·5.

From the figures given by various supply engineers and authorities it appears that the cost per mile of 11,000-volt 3-phase lines lies between about £300 and £600 plus about £50 per mile on account of wayleaves, compensation to tenants, tree-lopping, etc. The actual cost depends, of course, upon the size and material used for the conductor (usually copper or steel-cored aluminium), the span adopted (usually about 350 feet), and the type of pole used, as well as upon the type of country to be covered, the earthing arrangements, and so on. Spurs for isolated consumers cost rather less than for the main lines (say) £250 to £300 per mile.

For 3-phase 4-wire low-tension distribution the cost per mile of overhead lines is from about £400 to £600, according to size of conductor.

Wooden poles, with steel-cored aluminium conductors, spans of 350 feet or more, independent earthing of poles instead of the alternative of a continuous earth wire running above the conductors, and pin-type insulators appear to be fairly generally accepted as giving the cheapest form of line. Short spans enable a much cheaper pole to be used, but the erection, insulation, and wayleave costs usually more than counterbalance the saving on poles. Galvanized-steel conductors form a cheap line for short-distance supply of small loads.

It is admitted that a continuous earth wire gives valuable protection from lightning, whereas independent earthing of poles does nothing in this direction, but a number of rural schemes have adopted the latter for cheapness without, so far, encountering serious difficulties due to lightning.

A number of engineers favour single-phase supplies, especially for spurs and supplies to isolated consumers and for low-voltage distribution, since this effects a considerable saving in lines, transformers, and switchgear. A 3-wire single-phase system, supplied from the 460-volt secondary of a transformer with the mid-point earthed to give two 230-volt supplies, is used for low-voltage distribution. Motors for power work can be 460-volt, connected across the outers, but a disadvantage is that such motors are more expensive than 3-phase. Tail-end boosters are used for voltage regulation on single-phase lines of appreciable length.[1] Another suggestion which has been made is the adoption of 33,000 volts for the mains forming the backbone of the rural scheme (instead of 11,000 volts) as well as for the main feeders, an advantage being the improved voltage regulation obtainable.

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[1] "A Review of Recent Developments in Rural Electrification," by D. Ross, *Journal I.E.E.*, vol. 77, p. 797; see also "Single-phase Distribution," by J. V. Brittain, *Distribution of Electricity*, May, June, and July 1934.

Although the cost per mile of overhead lines is only about one-third that of underground cable, the latter has advantages as regards freedom from interference and better electrical performance than overhead lines. Attempts are now being made to reduce the costs of laying such cables in order that they may compete with the overhead lines. A trench-digging machine has been developed which excavates a trench 8 to 18 inches wide and up to 4 feet 6 inches in depth, and this is followed by a tractor hauling a mechanized cable-drum carriage, the cable (11,000-volt) being specially designed for rural work.[1]

Tariffs

The question of the tariff to be adopted for rural electricity supply is, of course, an extremely important one, and is, at the same time, one upon which it is difficult to make a decision ensuring satisfactory results. The two most essential features must be the relationship of the tariff to the costs of supply and its action as regards encouragement of the consumer to take an increased amount of electricity. Other factors of importance are the purpose for which a supply is given and the financial circumstances of the consumer. Although an enormous amount of discussion has taken place upon the subject, it is still impossible to give a single tariff which is ideal for all rural supply purposes.

It is common knowledge that the total cost of supply is made up of two parts, one of which is fixed and the other dependent upon the number of units supplied. Here again, however, it is not easy to say exactly what charges are really fixed and what shall be allocated as running charges. Bulk supply tariffs are almost always two-part, based upon the kilowatts of maximum demand and upon the number of units consumed. This is, perhaps, the obvious tariff for such supplies, since there exists a definite fixed cost proportional to the plant which must be installed in the generating station to deal with the maximum demand as well as a definite unit cost.

Such a tariff is not, however, suitable for rural distribution without considerable modification. It has been pointed out already that more than half of the total costs are those due to transmission and distribution. Now, while these again may be divided into two parts—fixed and running—the fixed part is by no means exactly proportional to the maximum demand on the system. The costs of certain parts of the system, such as those of transformers, switchgear, and conductors, are largely influenced by the probable power demand, but many of the costs, such as those for erection of overhead lines, rates, wayleave, and compensation charges, etc., are incidental to the construction of the system itself and are largely independent of the power supplied.

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[1] Callender's Cable and Construction Co., Ltd.; also "Rural Cable Systems," by P. V. Hunter and H. J. Allcock, *Electrical Review*, May 29th, 1936. "A Cable-laying Plough," by Sir B. E. Greenwell, Bt., *Electrical Review*, May 29th, 1936.

The charge made to a consumer must, if it is to bear a close relationship to supply costs, still be in a two-part form, but the fixed, or, more properly, "service" charge cannot best be made in the form of a kilowatt charge. The expression[1] already mentioned (pp. 48 and 223) for the cost per unit is :

$$\text{Cost per unit (in pence)} = \frac{1{,}140}{\text{No. of units}} + 0{\cdot}73,$$

or, total cost of supply to any particular consumer, is 1,140 + (0·73 × number of units consumed per annum). This expression is of the form $X + NY$.

Where X = fixed cost per annum
Y = cost per unit supplied
N = number of units supplied per annum.

It would seem, therefore, that a simple method of charging for energy supplied in order to cover the costs of the supply would be a fixed charge of 1,140*d.* (i.e. £4 15*s.*), together with a unit charge of 0·73*d.* Such a procedure would, however, lead to very high charges per unit in the case of small consumers, and the tariff actually adopted must result in the reduction of the fixed charge in the case of such consumers, the loss of revenue incurred being made up by a greater fixed charge to the larger consumers. The net result of this is to make the actual cost per unit (reckoning both fixed and unit charges) more uniform than it would be if the simple tariff mentioned above were adopted.

It should be pointed out here that two factors which influence the cost per unit are the "load factor" and the "diversity factor," increase of the latter having the effect of increasing the former. By definition, load factor is the ratio :

$$\frac{\text{actual consumption in units per annum}}{\text{maximum demand in kilowatts} \times \text{number of hours in 1 year}}.$$

This factor is always less than unity and may be taken as between 0·2 and 0·25 (often expressed as a percentage, viz. 20 per cent. to 25 per cent.). Diversity relates to the times at which the individual maximum demands of the consumers occur. The diversity factor is the ratio of the sum of the individual maximum demands to the actual maximum demand upon the system. To take a very simple illustrative example, suppose that two consumers each took a load of 10 kW for 12 hours a day. Their individual load factors would each be 0·5 (or 50 per cent.). As regards diversity, if the two loads were taken for the same twelve hours in the day, the diversity factor would be unity, but if they occurred at different times without any overlapping the factor would be 2, since the sum of the demands would be 20 kW, while at no time would more than 10 kW be demanded from the supply.

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[1] From the paper (*loc. cit.*) by Dickinson and Grimmitt.

Considering again the expression for costs $X + NY$, if the load factor of the supply were doubled, the number of units consumed would become 2N, the values of X and Y being unaltered. The total cost would then be $X + 2NY$ and the cost per unit would fall to $\frac{X}{2N} + Y$. Tariffs should, therefore, be framed so that they assist in the development of a good load factor, and, by being suitable for different types of load, result in a high diversity factor, which, as already stated, will improve the load factor.

Actual Tariffs Used

With the object of obtaining a two-part tariff with a fixed or service charge which bears some relation to the consumption, various bases of assessment have been used. The commonest of these are:

Rateable value of the consumer's premises.
Floor area of the premises.
Number of rooms wired.
Total wattage installed for lighting and/or other purposes.

The unit charge should be, and usually is, not greater than 1*d.*, and it is an advantage, from a load-building point of view, if this can be reduced to ¾*d.* or less.

In addition to two-part tariffs, as mentioned above, there are flat-rate tariffs adapted to small consumers for lighting purposes only (when the rate may be as much as 6*d.* per unit or even more), and for general power purposes (of the order of 1½*d.* per unit). For certain special night or "off-peak" loads, when a load at almost any price is worth while to improve the load factor, very low tariffs are offered. These are often necessary in such cases in order that electricity may compete with alternative methods of carrying out the same work.

Some authorities offer, also, a graduated scale of a flat-rate type, the rate decreasing as the number of units used per annum, or per quarter, increase. In some cases, a further complication is added in the shape of a rate which falls in proportion to the units used per quarter per horse-power (or per kilowatt) installed.

The number of different tariffs which have been either adopted or suggested is, in fact, legion, and it would be pointless to attempt to do more than mention some of the commonest, as is done above. While no particular tariff fulfils all the requirements of an ideal one, it may be stated that a two-part tariff is, on the whole, better suited to rural work than a flat rate, provided a low unit charge does not result in an excessive service charge. It has been argued that a simple flat rate is most easily understood by the rural consumer, but, while this may be so, it is difficult to see how, with such a tariff, it will be possible to offer a rate sufficiently low to encourage high consumptions. For this purpose a low unit charge is essential, and it is the author's experience that the consumer tends to reckon costs of his consumption in terms of the unit charge and to neglect the service charge. Simplicity in a tariff is certainly a commendable feature, but it should not be difficult to get a normally intelligent consumer to understand both the necessity for and the working of a two-part tariff. Graduated tariffs, especially those with a rate depending upon the consumption per quarter per horse-power or kilowatt installed, appear to be rather too complicated for the majority of consumers, and might well be avoided unless absolutely essential.

In the case of premises situated at a distance from the distribution lines, as an alternative to the consumer bearing part of the cost of the necessary extension, a guaranteed consumption for the first three to five years of supply has commonly been asked for by the supply authority. Where necessary, this appears to be a satisfactory arrangement, the necessity for which is generally appreciated by the consumer. The normal basis of such guarantees is such that a gross revenue of 20 per cent. is obtained on the capital expenditure required for the extension.

Examples showing the order of the tariffs which have been used in rural areas are :

Flat Rates

Lighting	6*d*. to 8*d*. per unit.
Heating and cooking. .	1¼*d*. to 1¾*d*. per unit.
Water heating . . .	0·45*d*. (except during peak-load period) to ¾*d*. per unit.

Heating of public buildings	0·35*d.* to ½*d.* per unit.
Power	2¼*d.* per unit, descending according to number of units used in quarter to 1½*d.* or 1¼*d.* (Where the higher rates of 2*d.* per unit or more are in force, these usually apply only to the first 100 to 200 units per quarter, the rate then falling to 1¾*d.* or 1½*d.*)

Two-part Tariffs

The fixed charge for domestic purposes (or in some cases for all purposes) may be 15 to 20 per cent. of the rateable value of the premises, or (say) 3*s.* 6*d.* to 5*s.* per quarter for each room wired, or £1 10*s.* to £3 per annum for each 1,000 square feet of floor area. In the case of farm buildings, a reduced charge per 1,000 square feet of 15*s.* to £1 per annum is usually made.

The unit charges associated with such fixed charges vary from ½*d.* to 1*d.*, according to the magnitude of the fixed charge, or, in some cases, to the quarterly consumption; a descending scale for increased consumption being fairly common.

Future Development

The generation side of electricity supply having been placed on an efficient basis for the whole country by the construction of the Grid Scheme, it is on the distribution side that the greater part of any future progress must be looked for. This being so, it may be well to consider carefully the information brought to light by the recently issued *Report of the Committee on Electricity Distribution,*[1] in which it is stated that "we regard the problem of bringing a supply into the rural areas and extending it as widely as possible as being one of primary importance from a national point of view."

The difficulties confronting those responsible for rural electrification are not technical, nor are they, fundamentally, economic. If it were possible to start afresh as regards electricity supply for the whole country, with full powers to introduce a new code of regulations to divide the country into areas best suited as units for supply by a limited number of electricity undertakings, or, alternatively, to treat the whole country as a unit supplied under a single authority, there would be no difficulty in giving an electricity supply to urban and rural districts alike at a price which would compare favourably with that prevailing under existing conditions.

The nature of the development of electricity supply, the radical changes in methods which have taken place since its commencement, and legislation which, although attempting to keep abreast of the rapid developments, could not possibly be framed from the outset (in the year 1882) to build up a system which would be ideal under present conditions, have resulted in what is referred to in the McGowan Report as " the complex and chaotic structure of distribution " existing to-day. Both the dictates of economy on the part of supply undertakings and legislation which was " influenced by an insufficiently large and comprehensive outlook " have led to the electrification of the more densely populated municipal or local government areas, leaving that of the outlying rural areas to be undertaken later. While this policy may have resulted in an earlier, and possibly cheaper, supply being obtained by urban areas than would have been the case if larger areas, including rural districts, had been developed, it has placed the rural areas in a particularly disadvantageous position. Their electrification now raises questions of capital expenditure on what might appear unremunerative schemes and of burdens placed upon urban districts which would never have arisen had the development of both urban and rural districts been encouraged, by suitable legislation, to proceed along parallel lines. To quote the Report : " The parochial point of view, which the policy of early legislation tended to create, still persists, and is, in our opinion, one of the major difficulties to be overcome in any reorganization of distribution " ; and again : " Subsequent experience has shown that it was a mistake to envisage successful development of large areas if such development was to be divorced from the urban centres of population in such areas." It is pointed out, also, that the association of a rural area with an urban one would not necessarily be detrimental to the latter, since a greater diversity of load, and a consequently increased load factor, would be obtained, while in the rural area the cheaper construction possible with overhead lines, as compared with cables, largely offsets the disadvantages consequent upon the lower density of population. In reviewing the present situation the Report states that in 1933–4 there were 627 undertakers, in addition to the Central Electricity Board, supplying electricity in this country, and that of these, more than 400 sold individually less than 10 million units per annum, the aggregate sales of these small undertakings representing less than 10 per cent. of the total electricity output of the country. The conclusion is reached that " a substantial measure of simplification and co-ordination of the present structure is necessary if the fullest measure of development is to be achieved throughout the country in the future."

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[1] Issued May 1936, H.M. Stationery Office, price 2*s.*

In determining a basis for such reorganization, that of public control through regional boards is considered, but it is stated that the fact that control of generation and main transmission has been vested in the Central Electricity Board is not sufficient proof that a similar basis would be satisfactory for distribution. An important difference between generation and distribution is that commercial enterprise plays a much more important part in the latter case than in generation, where the problems to be faced are very largely technical. Reorganization on a public control basis is not felt to be justified, and the basis recommended is that of concentration of distribution in the hands of a comparatively small number of existing large and efficient undertakings with the absorption of the small and less efficient ones.

Where duplicate powers of supply exist in the same area, these are to be eliminated, since, in such cases, both undertakings lose the benefit of diversity of load which is so essential to economic working.

The advantages claimed for large undertakings are briefly as follows:

(1) The more efficient layout of the high-voltage system consequent upon the elimination of boundaries with the more comprehensive area and economy of capital expenditure on the construction of the system.

(2) Diversity of load, and increased load factor, due to the inclusion of a greater number of different types of load within the same area.

(3) Financial resources of sufficient magnitude to allow of procedure with development work, including extension of mains, hire, hire-purchase, and assisted wiring schemes, in areas which may not be immediately remunerative.

(4) The possibility of negotiating more favourable contracts of material owing to the larger scale of the purchases and greater standardization which results in lower costs of production.

(5) Possibility of employing more highly qualified executive officers owing to the greater financial resources allowing attractive salaries to be offered, together with a greater degree of specialization amongst the staff instead of one person having to be responsible for several branches of the work.

In the event of future legislation enabling the recommendations of the McGowan Committee to be carried out, there is no doubt that the reorganization on the lines suggested will pave the way towards more complete electrification of the rural areas. There will remain, however, the problem of achieving reasonably low distribution costs per rural consumer, unless the rural district is to remain as a burden upon the reconstituted supply area.

The Report makes a number of suggestions regarding the reduction of these costs, the more important of which are mentioned below. It is interesting to note from the graphs, given in the appendix, of average revenue per unit sold and of distribution costs per unit sold, plotted in each case against annual consumption per consumer, that the following formulæ apply very closely:

$$(1)\ \begin{array}{r}\text{Average revenue in}\\ \text{pence per unit sold}\end{array} = \frac{1{,}400}{\text{units sold per consumer}} + 0{\cdot}52.$$

$$(2)\ \begin{array}{r}\text{Distribution costs in}\\ \text{pence per unit sold}\end{array} = \frac{890}{\text{units sold per consumer}} + 0{\cdot}127.$$

These average results are for all authorized undertakings for the year 1933–4, bulk supplies being excluded. To take a simple example: When the average consumption per consumer is 1,400 units, the corresponding revenue is 1·52*d*. per unit, while the distribution cost is 0·763*d*. per unit, or almost exactly 50 per cent. of the revenue. For double this consumption the figures of revenue and distribution cost are 1·02*d*. and 0·445*d*. per unit respectively.

The importance of increasing both the number of consumers and their annual consumption is obvious.

Suggestions regarding Load Building and Reduction of Distribution Costs

Suggestions made in the Report are as follows:

(1) Capital for distribution purposes should be raised on the best possible terms, since capital charges are responsible for about 50 per cent. of the total distribution costs, while 1 per cent. reduction in capital charges is equivalent to a reduction of 6½ per cent. in revenue.

(2) The fullest use should be made of capital by aiming at the connection of all premises along the route of the mains and by encouraging increased use of the supply.

(3) Supply authorities should adopt more widely standard types of cable to reduce cable costs, which form a large item in the total capital expenditure required.

(4) Efforts should be made to obtain the greatest possible

diversity of load so as to increase the load factor, which is at present under 30 per cent. in the case of some 69 per cent. of supply undertakings.

(5) To improve load factor an increase in the number of cookers and water heaters should be aimed at.

(6) Under-eaves construction would simplify the question of supply to small premises, and it is recommended that the necessary powers should be granted to undertakers in appropriate cases.

(7) Two-part tariff prepayment meters might encourage increased consumption in the case of small consumers.

(8) Facilities for hire and hire-purchase of appliances and for assisted wiring should be offered in the case of small consumers (over 20 per cent. of the total number of undertakings had no assisted wiring schemes in 1934).

(9) A larger number of showrooms and the extension of canvassing systems and demonstrations are necessary to increase sales and supplies (some 24 per cent. of the undertakings in 1934 had no showrooms and about 42 per cent. no canvassing system). An adequate service staff to attend to complaints from consumers should also be maintained.

(10) Standardization of the type of system (A.C. being recommended) and of voltages is desirable, though compulsory standardization is not recommended.

(11) Supply authorities should work in close collaboration with the various local authorities and rural associations to facilitate the granting of wayleaves and with the object of obtaining greater appreciation of the benefits of electricity supply. It is suggested also that powers might be given to local authorities to participate in guarantees regarding consumption when connection of outlying villages is contemplated.

(12) Some standardization of methods of charging for electricity is essential as a preliminary to uniformity of actual charges.

(13) All authorized distributors should be required to offer an approved statutory two-part tariff as an alternative to a flat rate. It is pointed out that in some districts the existing flat rate for lighting is too low, and that this should be fairly high in order to encourage changeover to the two-part tariff.

(14) The basis of the fixed charge in the case of two-part tariffs should be either floor area or rateable value, the preference being for the former, except that in the case of farm buildings some modification might be necessary. Undertakers should publish

the scale of fixed charges used by them. A unit charge of ½*d.* is sufficiently low to encourage consumption on the part of most consumers.

(15) Increased consultation between the undertakers in different areas is desirable, as is the fostering of a greater competitive spirit among the undertakings. Publication by the Electricity Commissioners of the more important statistics relating to progress made in different districts might help in the latter direction.

In conclusion, it appears to the author that progress in rural districts, and particularly in the case of farms, will be influenced very largely by the canvassing methods adopted. In spite of the wide publicity which has been given to the subject of rural and agricultural electrification during the last year or two, there is still a very large number of farmers who have no conception of the benefits which they would receive from an electricity supply or, at most, consider only the possible advantage of electric light. It must be realized that most of the publicity given through the ordinary channels fails to reach the farmer, who has few facilities for obtaining information on the subject and little time or inclination for the study of published matter.

In most cases direct approach on the part of the representatives of the supply authority is necessary, and it should also be pointed out that a considerable amount of tact is essential. Insufficient has been done in the past to call the attention of farmers, whose premises are already connected to the supply but whose use of electricity is confined almost entirely to lighting and small domestic purposes, to the many power applications available. Demonstration vans and conferences and demonstrations at electrified farms have certainly helped, but an increased use of the former is essential, and, whenever possible, a demonstration of the application of an electrical drive to existing machines on the farm of the consumer (or potential consumer, in which case a temporary supply may be obtained from a generator carried on the demonstration van and driven by its engine) should be made. Such direct evidence of the possibilities on his own premises is likely to be much more convincing to the average farmer than any amount of explanatory literature or even than demonstrations carried out at specially selected farms.

INDEX

A

Accidents, electrical, 92
Accounts, quarterly, 140
Agricultural conditions, summary of present-day, 17
  industry, data relating to, 11
  wages and prices, 12
  workers, number of, 3, 12
Air heating of garden frames, 195
Alternating current, 90
Alternator, 90
Ampere, 94
  hour, 95
Annual consumption of electricity, 35, 223
  per mile of route, 53
  per square mile, 51
Area, rural, 9
Argentina, rural electrification in, 69
Artificial drying, 180
Assisted wiring, 50, 62, 216
Atmospheric potential, 202
Aylesbury area, 55

B

Barn machinery, 142
  drive of, 31
Bedford rural area, 36, 39, 47, 55
Belgium, rural electrification in, 66
Blacksmith's equipment, 42
Board of Trade unit, 76
Boiling rings, 119
  water, energy consumption in, 78
Bottle washer, 166
Breakfast cookers, 109
British thermal unit, 77
Brooders, 169

C

Cables, cross-section of, 215
  flexible, 210, 214
  lead-covered, 207
  soil-heating, 189
  tough-rubber-sheathed, 207
  underground, 230
Canada, rural electrification in, 68
Capital costs of distribution, 54, 59
Central Electricity Board, 235
Chester rural area, 37, 38, 47, 55
Circuit, the electric, 87
Circuit-breakers, 99
Clipping machines, 164
Coffee percolators, electric, 120
Competitive forms of drive, 151
Conduit systems, 207
Connection to supply, method of, 96
Consumption of electricity :
  annual, 35
  increase of, 60
  per head of population, 67
Conveyors, pneumatic, 179
Cookers, breakfast, 109
  electric, 107
  power taken by electric, 111
  thermal-storage, 109
Cooking apparatus, electric, 117
  comparison of oil and electric, 116
  costs of electric, 115
  energy consumption in electric, 115
  hotplate, 113
  procedure in electric, 112
Corn-growing farms, 26
Cost of domestic electricity, 140
  of supply, 225
  per unit, economical, 220
Coulomb, 95
Crops, drying of, 179
  handling and treatment of, 176
  transportation of, 65
Cultivation, changes in, 16
Current, alternating, 90
  direct, 90
  electric, 94
Current-carrying capacity, 94

D

Dairy equipment, electrically operated, 166
  farms, size of, 26
  work, 162
Danger to consumer, 92
Demand per consumer, 48
  per head of population, 45
Demonstration farms, 69
  vans, 61, 239
Denmark, rural electrification in, 66
Density of population, 219
Diesel engines, 152
Direct current, 90
Distribution costs, 219
  reduction of, 237
Distribution lines, cost of, 54

Distribution lines, low-tension, 228
Distribution Report of Committee on Electricity, 219, 234
Diversity factor, 85
Domestic appliances, summary of, 139
  load, 103
  power, 33
Drive, choice of method of, 143
  comparison of motor and engine, 152
Drumotor, G.E.C., 149
Drying, artificial, 180
Dumfriesshire area, 55

E

Earth plates, 93
  resistance, 212
  wire, 214, 229
Earthing arrangements, 211
  of wiring, 206
Earth-leakage trips, 212
Economic supply, 219
Economical cost per unit, 220
Efficiency, 75
Egg-grading machine, 172
  testing lamps, 172
  washing machine, 174
Electric fire, 91
  motors, power consumption of, 79
  pressure, 58
  shock, 92
Electrical osmosis, 201
Electricity, annual consumption of, per acre, 40
  Commissioners' Reports, 29, 30, 31, 35, 36, 39, 40, 44, 45, 47, 49, 51, 57, 106
  consumption per acre, 66
  price of, abroad, 13, 63
  supply, three-phase, 143
  tariff, two-part, 35, 60
  total annual consumption of, in rural districts, 44
Electrification of mining.
Electrified farms, number of, 7
Electroculture, 200
Elevators, 179
Employment in various industries, 11
Energy, 73, 79
  conservation of, 74
  kinetic, 74
  measurement of, 85
  potential, 73

F

Fans, 128, 198
  incubator, 171
Farm processes, 141
Farms, corn-growing, 26
  dairy, size of, 26
  number of, 4
  sizes of, 20
  types of, 20
Faults, 93
Fire, risk of, due to short-circuit, 98
Fires, electric, 122
Foreign competition, 12, 13
France, rural electrification in, 64
Fuel consumption of engines, 154
Fuses, 97
Future developments, 234
Future prospects of electrification, 57

G

Gas engines, 152
Generation and transmission, comparative costs of, 6
Generator, 90
Germany, rural electrification in, 64
Geysers, electric, 130
Grain drying, 185
Grass drying, 181, 183
Greenhouse heating, 196
Grinding costs, 158
Groomers, 164

H

Handling of crops, 65, 176
Heat equivalent of electrical energy, 77
Heaters, immersion, 117
  tubular, 124
Heating, costs of electric, 127
  devices, 128
  electric, of rooms, 122
  greenhouse, 196
  power required for electric, 126
  water, 129
Hoists, 177
Holland, rural electrification in, 66
Home-produced and imported food, 16
Hop drying, 185
Horse labour, 19, 27
Horse-power required for barn machines, 142
Horticulture, application of electricity to, 188
Hotplates, 108, 111, 113

I

Illumination, intensive, for plants, 199
Immersion heaters, 117, 196
Imported food, 16
Incubators, 168
India, rural electrification in, 69
Individual drive, 145, 165

Industries, rural, 41
Inspection lamps, 162, 216
Installation costs, 104
Insulation, 93
Irons, electric, 137
Irrigation, 65, 67, 70
Italy, rural electrification in, 67

J

Junction boxes, 210

K

Keith-Blackman-B.T.-H. system, 198
Kettles, electric, 118
Kilowatt, 34, 101
  hour, 35, 76

L

Lamps, electric, 104
Large power consumers, 49
Lead-covered cables, 207
Lighting, electric:
  advantages of, 104
  costs of, 104
  in cowsheds, 162
  in farm buildings, 141
  in poultry houses, 174
  on farms, 31
Lighting load, 221
Line shafting, 145
  in dairy, 165
Live wire, 92
Load, domestic, 103
  effect of upon efficiency, 80
  horticultural, 188
Load building, 237
Load factor, 53, 63, 66, 83
  on farms, 26
Loans for electric installations, 218

M

Manual labour, 19
Manure pump, 160
Marketing boards, 13
Maximum-demand tariff, 84
Measurement of power and energy, 85
Mechanization of farming, 15
Meter readings, 85
Mid-Cheshire area, 47
Milking machines, 63, 162
Mining, electrification of, 4
Model electrification scheme, 52
Moisture, effect of, upon insulation, 94, 98
Motor size, choice of, 82
  speeds, 149
Motors, A.C., 143
  electric, 101
    advantages of, 155
    initial and working costs of, 150
    power consumption of, 151
    protection of, from overload, 100
Multiple earthing, 211

N

National Electricity Grid, 6, 58, 94, 101, 219, 234
New Zealand, rural electrification in, 62
Norway, rural electrification in, 66
Norwich rural area, 47, 55

O

Occupied areas of supply, 47, 51, 56
Ohm, 96
Ohm's law, 96
Oil, 19
  cooking, 103, 116
  engines, 19, 29, 151
  heating of incubators, 169
  lighting, 103, 106
Osmosis, electrical, 201
Output per acre, 24
  per man, 24
  per person in various industries, 14
Overhead lines, 215, 228
Overheating of appliances and cables, 93
Overloading of motors, 80

P

Panel heating, 128
Paraffin engines, 152
Parallel method of connection, 96
Parishes, rural, number of, 52
  population of, 52
Petrol engines, 152
Ploughing, electric, 28, 40, 64, 67
Population, density of, 9, 51
  rural, 9
Portable motors, 147
Potato peelers, 120
Poultry farming, 167
  equipment, 175
Power demand, magnitude of, 29
  domestic, 33
  electric, 100
  forms of, 19
  measurement of, 85
  total demand for, on English farms, 34
Prepayment meters, 216
Pressure drop, 87
Private electrical plants, 7

Production per head of labour, 15
Protected-type plugs, 216
Protection of kettles, 118
  of motors, 144
Pumping, 65, 67, 159
  energy consumption in, 159
  installations, 44

R

Radiators, electric, 122
Rate of connection to supply, 50
Rated horse-power, 80
Refrigerators, 120
Regulations, 59
Resistance, electrical 89, 94
Revenue to the supply undertaking, 223, 225
Ring mains, 213, 228
Rothamsted experiments, 156
Running costs of electrical appliances, 79
Rural and urban undertakings, comparison of, 227
Rural area in Great Britain, 9
Rural industries, 41
  Bureau, 42
Russia, rural electrification in, 67

S

Saucepans, electric, 120
  for electric cooking, 113
Scotland, rural electrification in, 8
Series connection, 96
Shock, electric, 92, 98
  risk of, 211
Short-circuit, 95, 97
Showrooms, 61
Single-phase supply, 143, 211, 228
Size of farm, 20
  influence of, 24
Smallholdings, 21
  in Germany, 65
Soil-heating, 66, 68, 189
  energy consumption in, 193
Soil sterilization, 199
Specific heat, 193
Speeds of barn machinery, 143
  of motors, 83, 149
Spraying, 160, 187
Starters, motor, 101, 144
Sterilization of soil, 199
Sterilizing chests, 165
Storage water heaters, 131
Sunlight, effect of, upon insulation, 208
Sweden, rural electrification in, 66
Switch boxes, 210
Switches, 89
Switzerland, rural electrification in, 67

T

Tariffs, 14
  electricity, 222, 230
Temperatures, room, 125
Tenanted property, electric wiring of, 217
Terminals, 89
Thermostat, 112, 125, 132, 135, 169, 191, 195
Three-phase supply, 143, 211
Threshing, 22, 40, 65, 68
  costs, 157
Time switches, 89, 176, 196
Toasters, electric, 120
Tough-rubber-sheathed cables, 208
Tractors, 19, 27
  running costs of, 157
Transformers, 59, 64, 91, 162
  portable, 216
Transmission, 228
  and generation, comparative costs of, 6
  lines, cost of, 54, 63, 70
Tubular heaters, 124, 196
Two-part electricity tariff, 60, 225, 230, 234
Type of farm, influence of, upon size, 23, 26
Types of farms, 20
  employment on various, 21

U

Unit of electrical energy, 35, 76
United States of America, rural electrification in, 68

V

Volt, 58, 88, 91
Voltage, 58

W

Warming plates, 120
Washing, electric, appliances, 136
Water boilers, 117
  energy consumption in, 135
  heaters, 130
  heating, 129
Wattage, 34
Watt-hour meter, 85
Wattmeter, 85
Watts, 34, 100
Wayleaves, 59
Wiring, assisted, 216
  electric, for farms, 205
  systems, 207
Woodworkers' equipment, 42
Work, 73